HELSINKI UNIVERSITY OF TECHNOLOGY
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ANALYSIS OF THE CONTINENTAL EUROPEAN ELECTRICITY MARKET UNDER LIBERALIZATION

Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Engineering

Espoo, 20th May, 2005

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ABSTRACT OF THE MASTER'S THESIS

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The European Union aims at attaining efficiency improvements in the electricity sector through deregulation accompanied by market integration. The increased interdependence of national electricity markets brought by integration increases the market participants' need to understand the functioning of the electricity market of a larger region than a single country. The objective of this Thesis is to analyze how the supply, demand, and price of electricity are determined by electricity market fundamentals in the liberalizing Continental European electricity market. The research is of an exploratory nature, and it aims at improving the understanding of how this market functions. Economic theory constitutes the theoretical framework of the Thesis.

The main part of the research relies on the interpretation of statistical data concerning the market. The research also includes a literature review, where economic viewpoints regarding the development of the electricity market are considered, and these viewpoints are then compared to the direction that the decision makers of the European Union have taken. Ten Continental European countries are considered in the analysis. The Thesis analyzes the patterns in consumption, generation, and the price of electricity in each of the countries considered, as well as transmission between the countries. The countries are compared to each other, e.g., in terms of the electricity prices and the cycles and structures exhibited by the statistics on consumption, generation, and net exports. Interpretations of the observations are presented, and generalizing conclusions are drawn based on the analysis.

The analysis leads to the conclusion that Germany, France, Austria and Switzerland form a near-single-price region already, which implies that integration between these countries is already well under way in terms of prices. However, outside this region, transmission bottlenecks prevent price convergence. The integration of European electricity markets is still far from being completed, but it could be furthered by building additional transmission capacity and introducing well-functioning, market-based methods for congestion management. Improvements should also be made in market transparency, in order for the market to function effectively.

Keywords: electricity, integration, deregulation, Europe, microeconomics	Publishing language: English

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Euroopan Unioni pyrkii lisäämään sähkömarkkinoiden tehokkuutta markkinoiden vapauttamisen ja integraation avulla. Lisääntynyt integraatio ja sen myötä kansallisten sähkömarkkinoiden lisääntynyt riippuvuus toisistaan kasvattaa energia-alan toimijoiden tarvetta tuntea markkinoiden toimintaa yksittäistä maata suuremmalla alueella. Tämän diplomityön tavoitteena on analysoida, kuinka sähkömarkkinoiden fundamentit määrittävät sähkön kysyntää, tarjontaa ja hintaa liberalisoituvilla Manner-Euroopan sähkömarkkinoilla. Tutkimus on luonteeltaan eksploratiivinen ja pyrkii lisäämään ymmärtämystä näiden markkinoiden toiminnasta. Kansantaloustiede muodostaa teoreettiset puitteet, joiden varaan tutkimus rakentuu.

Tutkimus perustuu pääosin Euroopan sähkömarkkinoita koskevien tilastotietojen tulkintaan. Tutkimukseen kuuluu myös kirjallisuuskatsaus, jossa selvitetään sähkömarkkinoiden kehitykseen liittyviä taloustieteellisiä näkökohtia. Näitä näkökohtia verrataan sitten Euroopan Unionin päättäjien linjauksiin. Tutkimuksessa analysoitavaksi on valittu kymmenen Manner-Euroopan maata. Työssä analysoidaan kunkin maan osalta kulutusta, tuotantoa ja hintaa sekä maiden välistä sähkön siirtoa. Analyysin avulla pyritään selvittämään, mitä ominaisuuksia ja säännönmukaisuuksia näihin liittyy. Maita verrataan toisiinsa mm. sähkön hinnan suhteen sekä sen suhteen, millaisia syklejä ja rakenteita sähkön tuotantoon, kulutukseen ja nettovientiin tilastojen valossa liittyy. Tehdyille havainnoille esitetään tulkintoja ja analyysin pohjalta pyritään tekemään yleistyksiä.

Analyysin perusteella päädytään johtopäätökseen, jonka mukaan Saksa, Ranska, Itävalta ja Sveitsi muodostavat jo nyt alueen, jossa sähkön hinta on kaikkialla lähes sama. Integraatio on siis näiden neljän maan tapauksessa jo hyvässä vauhdissa sähkön hinnan osalta. Kuitenkin tämän alueen ulkopuolella sähkön siirron pullonkaulat estävät hintojen yhdentymisen. Euroopan sähkömarkkinoiden integraatio ei ole vielä läheskään valmis, mutta sitä olisi mahdollista edistää rakentamalla enemmän siirtokapasiteettia sekä ottamalla käyttöön hyvin toimivia markkinaehtoisia pullonkaulojen hallintamekanismeja. Markkinoiden tehokas toiminta edellyttäisi myös parannuksia markkinoiden läpinäkyvyyteen.

Avainsanat: sähkö, integraatio, markkinoiden vapauttaminen, Eurooppa, mikrotaloustiede	Julkaisukieli: englanti

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Espoo, May 2005

Rasmus Ahvenniemi

Abbreviations

Short form of countries

AT	Austria
BE	Belgium
CH	Switzerland
CZ	The Czech Republic
DE	Germany
ES	Spain
FR	France
GB	The United Kingdom
GR	Greece
HU	Hungary
IT	Italy
MA	Morocco
NL	The Netherlands
Nordic	The region formed by Denmark, Sweden, Norway and Finland
PL	Poland
PT	Portugal
SI	Slovenia
SK	The Slovak Republic

Power exchanges

APX	The Dutch power exchange
EEX	The German power exchange
EXAA	The Austrian power exchange
GME	The Italian power exchange
Nord Pool	The Nordic power exchange
OMEL	The Spanish power exchange
PolPX	The Polish power exchange
Powernext	The French power exchange

Organizations

ETSO	European Transmission System Operators
EuroPEX	Association of European Power Exchanges
IEA	International Energy Agency
UCTE	Union for the Co-ordination of Transmission of Electricity

Contents

1 Introduction

1.1 Background

The European electricity market is undergoing a process of liberalization. The European Commission has taken as one of its agendas the promoting of electricity market integration and deregulation within the European Union. In a strategy paper published in response to requests by participants in the "Florence" Forum on European Electricity Regulation, the European Commission (2004a, p. 3) states the following:

> *The Community is seeking to create a competitive market for electricity for an enlarged European Union, not only where customers have choice of supplier, but also where all unnecessary impediments to cross border exchanges are removed. Electricity should, as far as possible, flow between Member States as easily as it currently flows within Member States.*

According to the European Commission, improved cross-border flows will result in more competitive electricity markets in the European Union. A more competitive environment should improve economic efficiency in the sector and result in lower prices of electricity, and ultimately in higher overall economic growth in the European Union. The European Commission requires, however, that final customers receive a "secure, reasonably priced and continuous service" also under competition, and for this reason they conclude that the electricity market has to be "carefully monitored and appropriately regulated". (European Commission 2004a, p. 3)

According to the European Commission, there could be an interim stage in the integration process before total integration of the European electricity markets is achieved. In this interim stage, countries which are ahead of the overall integration process of European electricity markets, may form their own regional markets, involving, e.g., a few neighboring countries. The main reasons for these interim stages is that the member states of the European Union are not yet particularly well connected in terms of transmission capacity, while some have already adopted common harmonized rules. (European Commission 2004a, pp. 6–7) Total integration of the European electricity markets requires sufficient cross-border transmission capacity and a harmonization of the rules. Figure 1 illustrates the potential regional electricity markets within the European Union, during the interim stage of integration.

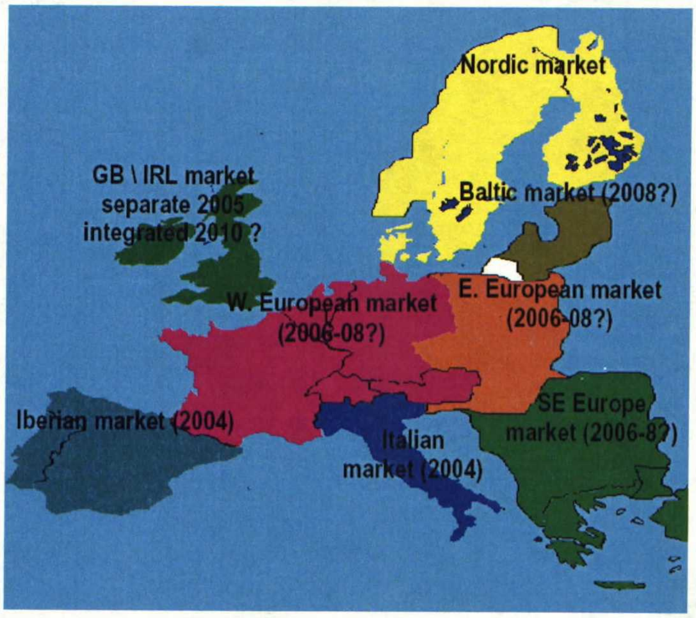

Figure 1. Potential regional electricity markets within the EU, according to the European Commission. (Source: European Commission 2004a, p. 6)

While the Nordic market is already fully integrated, the integration of, e.g., the West European market, consisting of Germany, France, Switzerland, Austria, and the Benelux countries might, in the European Commission's view, occur during 2006–2008. This would be of importance from the Nordic point of view, since the Nordic region is connected to the West European market with transmission lines of relatively high capacity, which makes the Nordic and West European markets interdependent.

Geographical regions are connected by transmission lines, which results in interdependences between the electricity markets of different countries. However, since transmission capacity is limited, the electricity markets of different countries or regions are not perfectly interconnected, and therefore significant price differences may occur between national markets. Because electricity markets are in most of Europe interconnected to some degree, but not perfectly, electricity markets are to some extent both national and international at the same time. Therefore, it makes sense to discuss both national electricity markets and the electricity markets of larger regions, such as Continental Europe.

The increased interconnectedness of European electric systems results in higher interdependence between national electricity markets as changes in electricity supply and demand in one country become propagated to other countries. This means that the price of electricity in each country is influenced by both foreign and domestic characteristics of demand and supply. Therefore, it becomes increasingly important for market participants in the energy sector to understand the factors (also known as *fundamentals*) that determine the supply, demand and thereby the price of electricity within larger geographical regions than just one country. This Thesis examines the fundamentals of the Continental European electricity market and attempts to explain how they influence the supply, demand and price of electricity.

From the Nordic point of view, the most important electricity market in Continental Europe is Germany, since the market is very large and is connected to Scandinavia by several transmission lines of high capacity. Therefore, the German electricity market has a strong influence on electricity prices in the Nordic countries. The electricity price in Germany is, in turn, influenced by its neighboring countries, and therefore not only Germany, but the whole of Continental Europe is interesting from the Nordic point of view.

1.2 Research objectives and methods

The main objective of this Thesis is:

To analyze how the supply, demand and price of electricity are determined by electricity market fundamentals in a liberalized Continental European electricity market.

Electricity price formation will be considered using the tools of economics, such as supply-demand frameworks and basic theory of international trade. In the case of constrained transmission capacity, price formation will be considered as an optimization problem.

The objective requires the examination of statistical data on consumption, generation, transmission and the price of electricity. The main method of data analysis in this Thesis is the interpretation of diagrams, such as time-series plots and histograms that illustrate the data. Qualitative observations are thus extracted from the numerical data, and these observations are then synthesized to form a picture of how the Continental European electricity market functions. Much of the analysis is based on observing time cycles in the data, since patterns, which replicate themselves at constant intervals, indicate that there are basic principles at work behind the statistics.

The objective of this Thesis is quite broad, since the geographical area of Continental Europe is large, and involves a large number of countries, most of which differ from each other in their fundamentals. The Thesis does not involve the building of a quantitative model, and its purpose is not that of forecasting. Rather, it should be seen as an exploratory research, where the structure of the present electricity market is analyzed on the macro level in order to give an overview of how the market functions. Thereby the Thesis can be a basis, on which to build possible future research, which may use quantitative models, when appropriate. In short, this Thesis is intended to shed light into which factors should be modeled and how. Important observations might escape the researcher's attention, if attention was at this point mainly directed towards building a quantitative model, at the expense of looking at the data and at the relevance of different factors. The constructing of a useful quantitative model would, in addition, require better availability of data.

There are public sources, which offer statistic data on the Continental European electricity market, but the availability of data is worse than in the case of the Nordic countries. For example, complete hourly or even daily data is not available on transmission between Continental European countries. Even though there are serious limitations to the availability of data, important observations can still be made, with sufficient accuracy, from the data that is obtainable.

The countries that are considered in this Thesis are the following: Germany, France, Belgium, the Netherlands, Spain, Switzerland, Austria, Italy, the Czech Republic and Poland. Some countries in Continental Europe are excluded from this research, because the small sizes of their electricity markets or their small volumes of cross-border transmission imply that their impact on the other countries is small. The countries that cannot be considered as being part of Continental Europe are excluded, with the exception that transmission between Germany and the Nordic countries is modeled, even though Nordic fundamentals are excluded from this research. The reasons for the inclusion of this electricity flow are its large volume, and its high importance from the Nordic point of view. In this Thesis, the term *"Continental Europe" will be considered as referring to the set of 10 countries listed above*. It should also be noted, that there are transmission lines that connect Continental Europe to other systems, but more specific examination of these has been excluded. This thesis does not consider regions smaller than countries or transmission taking place within a country's borders, since the availability of such specific-level data is poor. Figure 2 illustrates the Continental European electricity market and its connections. The circles in the figure represent countries, while the lines connecting them represent transmission lines.

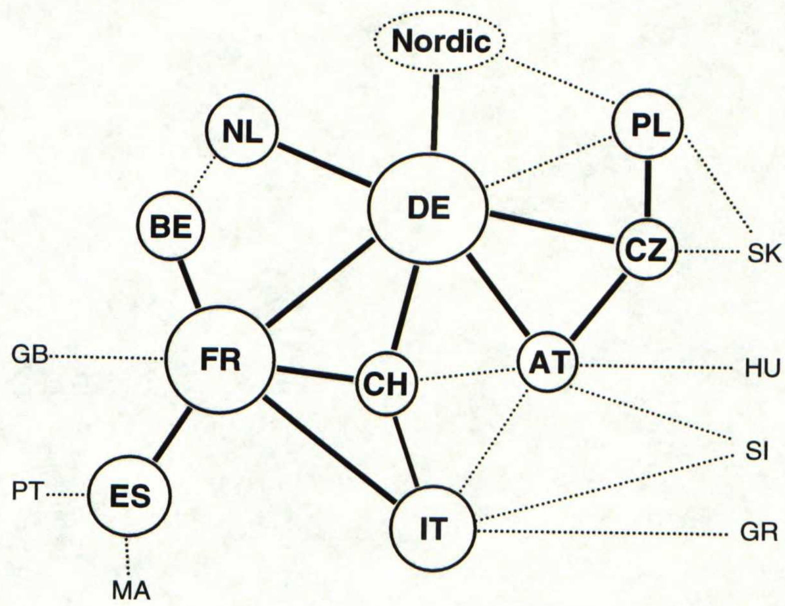

Figure 2. Interconnections in the Continental European electric system. The solid lines represent interconnections, in which the volumes of the electricity flows are particularly large. The countries studied in this Thesis are indicated with solid circles.

This Thesis considers the Continental European electricity market as it is at the present. For example the building of new interconnections or additional transmission capacity may change the situation, so that some of the conclusions of the model may not remain valid. At that a point, the analysis may have to be redone with new data. The European Union's institutions have agreed to give priority to a number of transmission grid enhancement projects. These include, among others, transmission lines between the Nordic countries and the Netherlands, between Poland and Germany, and between France and Belgium. (European Commission 2004b, pp. 4–25)

1.3 Structure of the Thesis

Chapter 2 examines the economic theory concerning the liberalization of electricity markets. The chapter provides a review of economic literature on electricity market liberalization, and describes the economic theory concerning the determination of the market equilibrium in an integrated market for electricity. Chapter 3 explains the current state of the Continental European electricity market. It considers how electricity market liberalization has been implemented in the European Union. The role of power exchanges is also considered, as well as the effect that electricity market integration will have on the market shares of the most important players. Chapters 4 and 5 consider the demand and supply fundamentals of the different countries, Chapter 6 considers transmission of electricity between the countries, and Chapter 7 analyses the price of electricity in these countries. Chapters 4–7 mainly rely on analysis of statistical data. As a synthesis of the knowledge gained in the earlier chapters, Chapter 8 sheds light into price formation in Continental Europe. It applies the theoretical tools presented in Chapter 2 to the knowledge gained from the data analysis in Chapters 4–7. In Chapter 9, the results are discussed, and some conclusions are drawn.

2 Economic theory of electricity market liberalization

2.1 Economic viewpoints

Electricity differs from most products in several aspects. First, the supply and demand of electricity may vary a lot from hour to hour, day to day and season to season. Since, in addition, electricity cannot be stored, there is always going to be some volatility in the electricity market (McDermott and Peterson 2002, p. 17). Second, electricity transmission capacity is often highly constrained, since building new transmission lines is expensive and time-consuming. This partly separates the markets of different geographical regions from each other, which may increase the market power of players in the regions. Third, the electricity supply industry may exhibit economies of scale, which would imply that it is not efficient to have a large number of companies in the sector. Furthermore, for the part of transmission and distribution, the industry is usually considered to be naturally monopolistic. Fourth, the demand for electricity is relatively inelastic, which increases the concerns of market power. Electricity is also a very important part of the infrastructure and therefore continuous supply of electricity is a vital requirement for a functioning modern society.

Because of the special nature of electricity, more regulation is imposed on it than on many other products. In order to prevent the use of monopoly power, pricing of electricity has traditionally been heavily regulated by the governments in Europe. Firms have been permitted to price such that they recover their costs and often, in addition, obtain some premium. However, in such a system the companies' incentives to keep costs down are low. (Doyle and Maher 1992, p. 64) Another problem with regulation is that price signals to producers and consumers are disturbed in such a system, which results in inefficient allocation of resources. Deregulation has been suggested as a remedy to these inefficiencies. This, however, requires the deregulated market to be competitive, since deregulation may not bring improvements, if there are players with extensive market power (Reitzes et al. 2000, p. 11).

The supply chain of electricity can be seen as consisting of four stages: (i) *generation*, i.e., the conversion of different forms of energy into electricity in power plants, (ii) *transmission*, i.e., the transportation of the electricity along high-voltage transmission lines, which constitute the national grid, (iii) *distribution*, i.e., the transportation of the electricity from the transmission network to consumers over medium and low voltage lines, and (iv) *supply*, i.e., the process of buying electricity in bulk and selling it to consumers (Palasthy 2002, p. 3).

It has been suggested, e.g., by Christensen and Greene (1976) that generation is not a natural monopoly anymore (the study considered the electricity sector in the United States between 1955 and 1970), and could therefore be opened up to competition without the fear of monopolization. Transmission, however, is by most considered a natural monopoly, which should be regulated in order to prevent the use of monopoly power (see e.g. Joskow 1999, pp. 16–17). Weiss (1975) suggested, that electricity companies should be vertically disintegrated so as to separate generation and transmission. Then, the generation stage could be opened up to competition, which should result in higher efficiency and lower prices. Newbery (1995, p. 41) is pretty much in line with Weiss's proposition. According to Newbery, the stages of transmission and distribution are natural monopolies, but generation and supply are "potentially competitive". Also Newbery suggests that the supply chain of electricity, or the "Electricity Supply Industry", should be vertically disintegrated. Vertical disintegration would, according to Newbery, allow the potentially competitive parts of the industry to be removed from regulatory oversight, which should bring gains in efficiency. This is the road taken by the Nordic countries: transmission and generation have been unbundled from each other, and generation has been opened up to competition, while the countries' TSOs are regulated by the respective states.

Nobel prize winner Vernon Smith (1996) goes a step further still, proposing that it is also difficult to justify regulation of distribution. He criticizes the argument, that distribution should be a regulated monopoly in order to avoid inefficient duplication. He motivates his critic, e.g., by arguing that "in other industries such duplication is the norm and widely applauded as providing diversity of service", and that it is totally normal, for example, for a neighborhood to be served by several supermarkets. Smith concludes, however, that "central coordination is necessary in electric power because electrons flow according to the laws of physics, not economics".

Grønli (2001) discusses experiences of the different regulatory regimes of the Nordic countries. When the electricity markets were deregulated in Norway, Sweden, Denmark and Finland during the 1990s, competition was introduced to generation and trade, while grid operations were left regulated. Grønli compares the light-handed approaches to regulation of grid operators applied in Sweden and Finland to the heavy-handed approaches applied in Denmark and Norway. He concludes that one cannot appoint a single best regulatory model of those considered, because regulators may have different objectives.

McDermott and Peterson (2002, p. 18) criticize attempts to restructure the electricity market (particularly in the United States), in which the market has been "stripped of its essential tool – the price mechanism". They argue that it is not at all surprising that markets fail to operate effectively in situations where "price freezes and price reductions have reduced the demand side of the market to a near nonexistent component of the market process". They also state that in order for markets to function effectively, there has to exist a spot market as well as a market for future delivery periods.

Hira and Amaya (2003) compare the efforts to integrate the energy markets in Europe, Central America and South America in order to find out whether one of the models of integration is significantly better than the others. They argue that while Nord Pool is an important model for the regulatory design of an integrated market, it cannot be easily applied to countries that have different energy profiles in terms of resource endowments and domestic regulation. They propose that a successfully integrated market requires (i) adequate infrastructure, (ii) common regulatory principles and a common regulatory authority, and (iii) "customization of regulations toward the particularities of a region's energy resources and the actors that dominate the national electricity markets".

All do not agree with the agenda of deregulation. Blauvelt (2004), while not being altogether against deregulation, wants questions to be raised about its benefits and costs. He claims that deregulation itself may not have contributed much to the lower prices observed in certain deregulated countries, but that the reasons may lie in "other significant factors", such as fuel prices and increased efficiency. He also claims that "the uncertainties brought by deregulation have brought a decline in capital investment in the regulated sectors of the market, transmission and distribution". Newbery (2002) proposes that liberalization of electricity markets may even lead to rising prices, as generators become able to use their market power – that is, unless the market is at the same time made more competitive by expanding transmission capacity and ensuring adequate generation capacity. Penn (2000) argues that neoclassical economics and its deregulation-promoting implications in the electricity sector are based on assumptions and myths that have no ground in reality. The "greatest deregulation myth", according to Penn, is that "a competitive market will take care of everything if only it is freed from regulations". He claims that the use of monopoly power, which deregulation may enhance, is as large a threat to market efficiency as "outdated regulations", and he also criticizes, e.g., the price peaks that may occur in a deregulated market. Joskow (1999, pp. 16–17) claims that the market is unable to provide the sufficient incentives for needed transmission network enhancements. He argues that while market forces are able to bring more generating capacity in the system, they are unable to draw investments into new transmission capacity.

The main concern of the critics of deregulation is that deregulation might result in the power companies' exploitation of market power, and thereby in welfare losses. This, however, cannot happen if markets are truly competitive. Competitiveness can be increased by promoting the integration of the electricity markets of different regions into one single market – this will diminish each player's market share and thereby reduce their ability to use market power. This road to liberalization is supported, e.g., by Newbery (2002, p. 926), who proposes that the liberalization of electricity markets is best supported by increasing transmission capacity, since this should "increase the number of generators competing against each other, dilute market power, and reduce the need for regulatory market intervention".

Integration of electricity markets may bring other benefits as well, in addition to increased competitiveness. Gegax and Tschirhart mention, that with "power pooling", reliability of service can be kept on a particular level with less generating capacity, which allows for cost savings in reserve generating capacity. Another improvement brought by power pooling is that it allows demand to be met with the least-cost generating source available. (Gegax and Tschirhart 1984, p. 1078).

2.2 Price formation in free-trade equilibrium

When no constraints to trade (physical constraints, such as limited transportation capacity, or political barriers to trade, such as tariffs) are present, price will be determined in free-trade equilibrium. A two-country case of free-trade equilibrium is depicted in Figure 3. The basics of international trade theory are explained in numerous textbooks (see e.g. Pugel and Lindert 2000).

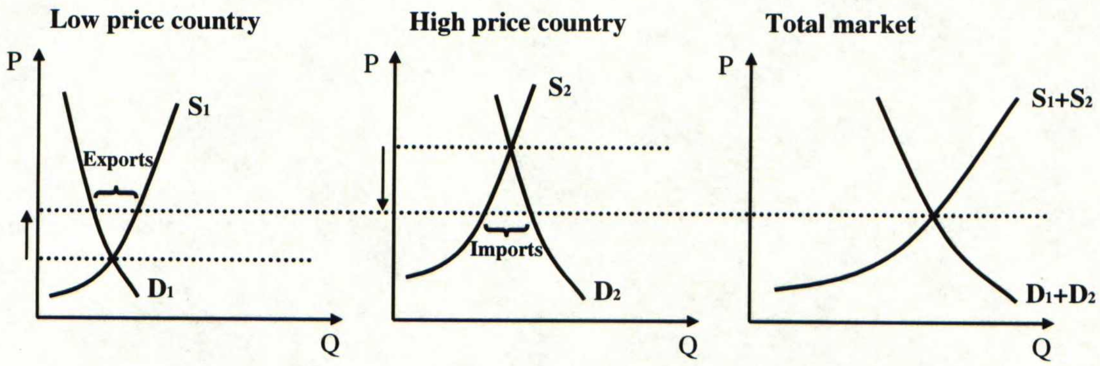

Figure 3. A two-country case of free-trade equilibrium.

In a situation with no trade, each country has its own, separate market in which price is determined in a national supply-demand equilibrium. The opening up of trade between countries integrates the national markets into one total market. In this total market, price is determined in a supply-demand equilibrium, at which the aggregated supply and demand curves of the countries involved intersect. Thus, prices are equalized between the countries: prices rise in the former low-price countries, and prices fall in the former high-price countries. At the new international price, the quantity supplied in the former low-price countries is greater than the quantity demanded. Respectively, in the former high-price countries, the quantity demanded is grater than the quantity supplied. In free-trade equilibrium, the surplus production of the former low-price countries is exported to the former high-price countries. It should be noted, that the supply and demand curves are dynamic, i.e., they shift and change their form as time passes. Also, the supply and demand curves themselves cannot be observed. Only the equilibrium price and volume can be observed.

2.3 Impact of transmission capacity constraints

If cross-border trade of a product is constrained, prices are determined separately for each country, in the respective national supply-demand equilibrium. There may then be *some* trade between the countries, but not enough in order for prices to equalize. Trade is therefore unable to create a totally integrated market.

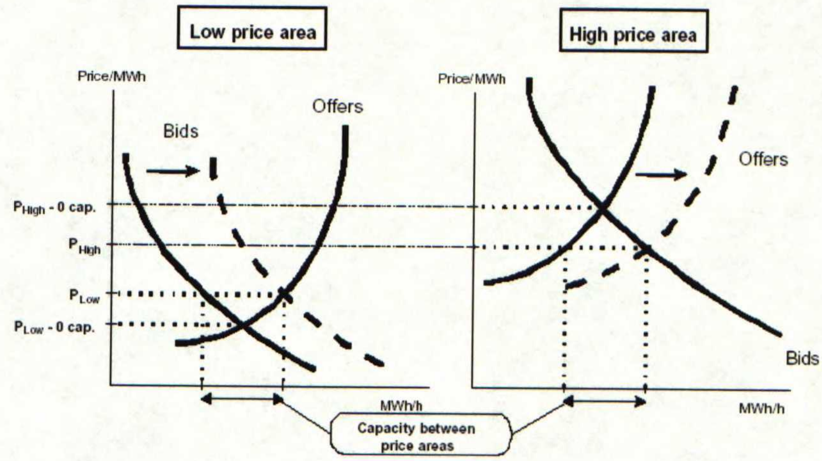

Figure 4. The case of limited transmission capacity. (Source: ETSO 2001, p. 6)

A situation of constrained cross-border trade is depicted in Figure 4, which considers a two-country (or "two-area") case of electricity trade, where transmission capacity is limited. Exports from the low-price area to the high-price area, constrained by transmission capacity, increase the demand perceived in the low-price area and increase the supply perceived in the high-price area. Therefore, prices rise in the low-price area, and prices fall in the high-price area. However, in contrast to the case of free-trade equilibrium, prices do not converge enough in order for the price difference to disappear. It should be noted, that while transmission capacity is always limited, this does not imply that the market always has to be fragmented. If transmission capacity is sufficient to accommodate all requested flows between the countries, the case of free-market equilibrium applies, and prices equalize.

When transmission capacity of an interconnection linking national transmission networks is insufficient to accommodate all electricity flows resulting from international trade requested by market participants, it is said that the interconnection is congested (EU 2003a, p. 3). Since there is at any time a maximum on the potential flow of electricity between two interconnected countries or areas, transmission capacity has to be allocated somehow among agents in the market who wish to engage in cross-border trade. There is a number of *congestion management* methods, which are used in the allocation of transmission capacity. A few of these methods are described below. Other methods will not be considered here, but descriptions of them are provided, e.g., by ETSO (2004, pp. 10–11).

In *explicit auctions*, transmission capacity is auctioned to market participants, separately from electricity. In *implicit auctions*, however, "transmission capacity is managed implicitly by the spot markets: network users submit purchase or sale bids for energy where they wish to generate or consume, and the market clearing procedure determines the most efficient amount and direction of physical power exchange between the market zones" (Consentec and Frontier economics 2004, p. 7). Thus, transmission capacity need not be allocated separately from electricity. *Market splitting* and *market coupling* are variants of implicit auctions. In implicit as well as explicit auctions, the transmission system operator owning the transmission line receives auction revenue from selling cross-border transmission capacity. Explicit and implicit auctions can both be considered market-based approaches.

When there are more than two countries involved in constrained international trade, the situation cannot be depicted with a diagram, such as Figure 4. In such cases, the market equilibrium has to be defined mathematically and cannot be defined simply by referring to intersection points of supply and demand curves. In the case of cross-border electricity trade, different models can be presented for finding the market equilibrium, depending on which method of congestion management is used. When implicit auction is used as the method of congestion management, the market equilibrium can be defined as the solution to an optimization problem. This problem is formulated so, that the objective function to be maximized is a benefit function representing economic welfare. The optimization problem can be formulated as is presented in Table 1. A mathematical formulation of the problem is presented in the Appendix.

Table 1. The market equilibrium under limited transmission capacity, defined as the solution to an optimization problem. (Source: ETSO 2002, pp. 11–12)

Max ***Economic welfare = consumer surplus + producer surplus***
***Subject to the following constraints*:** • The amount of generation allocated to each producer/consumer at a certain price does not exceed the volume of that generator's/producer's offer/bid • Total generation and consumption are equal • Transmission between regions is constrained by cross-border transmission capacity
***Decision variables*:** • The volume of generation/consumption allocated to each producer/consumer • Exchange of electricity between the countries

3 The current state

3.1 Liberalization in Europe

The road taken by the European Commission is that of liberalization of electricity markets through market integration. A strategy paper published by the European Commission (2004a, p. 3) states the following:

> *Improved cross border flows will increase the scope for real competition which will drive economic efficiency in the sector, leading to benefits for customers both in the business and the household sector in terms of lower energy prices, improved service and products tailored to their own needs. These benefits will feed through to higher overall economic growth in the European Union.*

Also European legislation, in the form of directives and regulations supports liberalization. Directive 2003/54/EC of the European Parliament and of the Council (EU 2003b), effective since 26 June 2003, establishes "common rules for the generation, transmission, distribution and supply of electricity" in the European Union. The directive requires the member states to ensure that consumers are free to purchase electricity from the supplier of their choice – non-household consumers should have this option from 1 July 2004 and all consumers from 1 July 2007, at the latest. It also requires transmission to be unbundled from the other stages of the supply chain, i.e., it shall be "independent at least in terms of its legal form, organization and decision making from other activities not relating to transmission". Allocation of cross-border transmission capacity is considered in Regulation 1228/2003 (EU 2003a), which aims at setting rules for cross-border exchange of electricity. It is stated in the regulation that congestion management shall be addressed with "non-discriminatory market-based solutions which give efficient economic signals to the market participants and transmission system operators involved".

The agenda of the European Commission as well as the legislation passed by the European Parliament and Council appear to be fairly well in line with most economists' views on the liberalization of the electricity market, as discussed in Section 2.1: Deregulation is seen as a factor contributing to efficiency, and market integration is seen as a way to increase competitiveness. It is believed that generation can be opened up to competition, if transmission, which is considered a natural monopoly, is unbundled from it. The importance of effective market signals is also emphasized.

The European Union does, however, face challenges in implementing a single European electricity market. These challenges are discussed, e.g., by Newbery (2001). He argues that there is some "unfinished business" in European attempts to increase competition in the sector. He claims, for example, that the agenda of restricting regulation to natural monopolies has resulted in too little attention being paid to dealing with the problems of undesirable unnatural monopolies in generation (Newbery 2001, p. 95).

3.2 Congestion management in Europe

Congestion management, i.e., the allocation method of transmission capacity, is a central issue in the integration of electricity markets. Transmission capacity can be allocated with one of a number of methods of congestion management, discussed in Section 2.3. In Europe, different methods are used at different national borders, as illustrated in Figure 5.

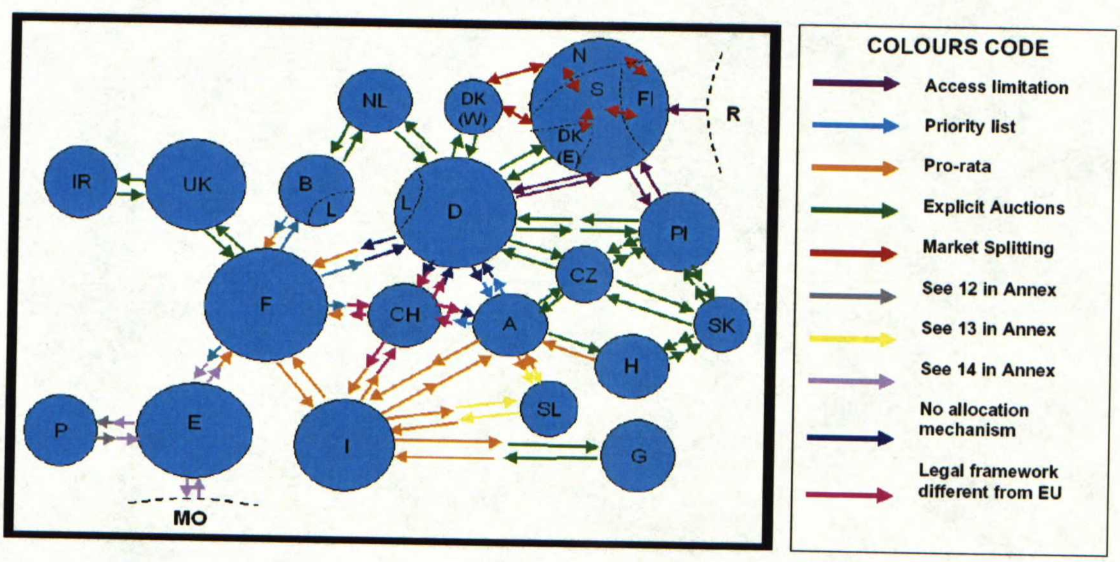

Figure 5. The use of different congestion management methods in Europe.[1]
(Source: ETSO 2004, p. 4)

[1] The explanation "see XX in Annex" refers to congestion management methods that cannot be categorized straightforwardly.

In Continental Europe, the method used most is explicit auctions, whereas market splitting is the only method used within the Nordic region. Other methods in use include pro-rata rationing, which is common in Southern Europe, and a number of other, less common methods. The fact that there is a large diversity of congestion management methods in use in Europe implies that the market is still developing. Harmonization of the methods and shifting towards market-based methods is likely to take place, as market integration proceeds. As mentioned in last section, the Regulation 1228/2003 (EU 2003a) requires market-based solutions to be adopted for congestion management. Therefore, methods other than explicit and implicit auctions should become less common in the future. In addition, other mechanisms than implicit auctions and its variants appear to be unable to produce results that reflect the market well. It has been observed, for example, that at the interconnection between Denmark and Germany, where explicit auctions is used for congestion management, electricity flows in the "wrong" direction (from the high-price region towards the low-price region) 25% of the time (Nord Pool 2005, p. 3). ETSO and EuroPEX (2004) propose that a variant of implicit auctions be used for congestion management in the Europe. It seems likely that in the future implicit auctions will be in use also outside of the Nordic region.

3.3 Power exchanges

McDermott and Peterson (2002, p. 18) state, that in order for electricity markets to function effectively, there has to exist a spot market as well as a market for future delivery periods. A spot market for physical delivery of electricity was proposed by Vickery in 1971. In a spot market for electricity, there is a distinct market price for each hour of the day, and these prices are determined on the market on the day before delivery. In contrast to spot markets, forward markets concern delivery during future periods. Contracts concerning future delivery of electricity can be negotiated between players, but a well-functioning market requires a place, where financial contracts for future settlement, i.e., futures contracts, can be made.

The role of a power exchange, as well as any exchange, is that of a centralized market place. Having a centralized market place increases market transparency, i.e., the market participants' ability to accurately observe the market price. Of the ten Continental European countries under view, Belgium, Switzerland and the Czech Republic do not yet have power exchanges. A power exchange does not, however, need to be limited by national borders, e.g., Nord Pool is the power exchange of four Nordic countries.

Power exchanges play an important role in congestion management, since they create the market for imported or exported electricity. In the absence of centralized power exchanges, cross-border transmission is conducted as bilateral trade between players in the different countries. In such cases, e.g. explicit auctions can be used for congestion management. However, when cross-border transmission is organized through power exchanges, also congestion management can be carried out by the power exchanges of the countries involved. Then it is possible to use implicit auctions as the method of congestion management.

Not all transactions in the electricity market are conducted on a power exchange, even if there is one in the country. In many cases, the volume of electricity sold on the national power exchange represents only a small fraction of all the electricity that is consumed in a country. The credibility of a power exchange requires the volumes sold on it to be large, so that it is a reliable price reference for financial trade. Figure 6 shows the volumes sold on power exchanges of Continental European countries as shares of total consumption in the respective countries. In addition to the countries presented in the Figure 6, also Spain and Italy have power exchanges. However, the volumes of their power exchanges are not comparable to the volumes of the other power exchanges, because Spain and Italy have set restrictions on transactions outside of the national power exchanges.

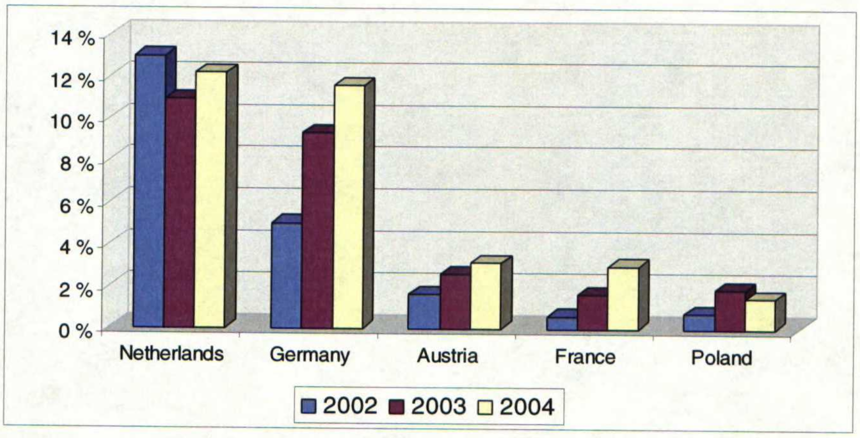

Figure 6. The volumes of power exchanges as shares of total consumption. (Sources: UCTE, APX, EEX, EXAA, PolPX, Powernext)

It can be seen in Figure 6, that the volumes traded on power exchanges as a share of total consumption are relatively small in the countries considered, in comparison to the Nordic region, where, e.g., in 2003 the volume of the spot market represents 31% of overall electricity consumption (Nord Pool). However, this share appears to be growing at least in Germany, France and Austria, and in the Netherlands it is already relatively high, even though still far below that of Nord Pool. In the Netherlands and Poland the growth of this share appears to have ceased, at least temporarily.

According McDermott and Peterson, "spot markets alone cannot provide the discipline that competitive markets need to operate efficiently". The completeness of the market requires a market to exist for future periods as well, and for all states of nature. There may exist on one hand centralized markets such as futures markets and on the other hand decentralized markets such as bilateral forward contracting. (McDermott and Peterson 2002, p. 18)

According to Levich (2001, pp. 377–379), there are many benefits to a futures market. First, the market is more transparent than bilateral forward contracting, since the market place is centralized and everyone sees the same market price. Second, since the products offered on a futures exchange are standardized, the liquidity of futures contracts is high. Third, there is very little risk of default of the other counterparty, since the other counterparty in every contract is a clearinghouse.

A clearing house may offer clearing services for contracts traded over the respective futures exchange as well as for standardized futures contracts traded in the OTC (bilateral) market. When the futures contract is traded over a futures exchange, the other counterparty is the clearing house, while in the case of futures contracts traded in the OTC markets, the other counterparty is another market participant. Nord Pool, for example, offers clearing services for both types of futures contracts.

A futures market requires a centralized market place, usually a power exchange. All European power exchanges do not, however, offer a clearing service for futures contracts at the moment. Of the Continental European countries considered in this Thesis, only the German, French, Polish and Dutch power exchanges offer clearing services for futures contracts. The Austrian power exchange offers clearing services for spread contracts.

3.4 Players

Figure 7 shows the largest generators' market shares in generation output in European countries. It can be seen in the figure, that in, e.g., France and Belgium, the market share of the largest generator is as much as 90%. In Italy and Austria, the largest generator's market shares are around 70% and 50%, respectively.

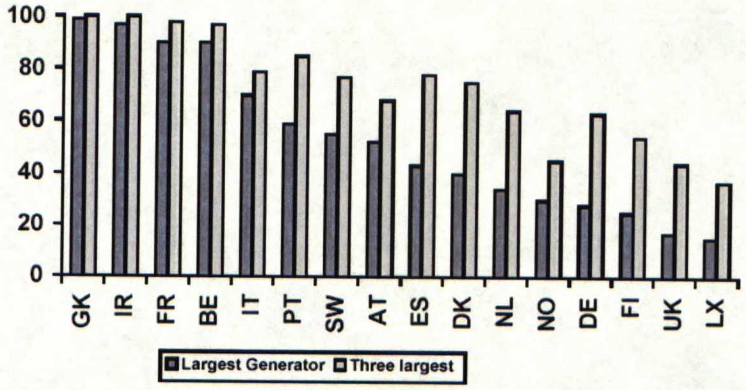

Figure 7. Market share in generation output. (Source: European Commission 2002, p. 108)

As was noted in Section 2.1, a main concern of economists is that deregulation might increase large players' ability to use market power. Unbundling transmission from generation may not result in efficiency gains if the generating companies' market shares are too large. However, the European Union's attempts of electricity market integration would, if successful, significantly reduce each player's market share. Figure 8 shows, what the players' market shares would be if calculated for a market area consisting of France, Germany, Austria and the Benelux countries. The figure can be seen as indicative of what the market structure would be in a single, integrated market involving these countries.

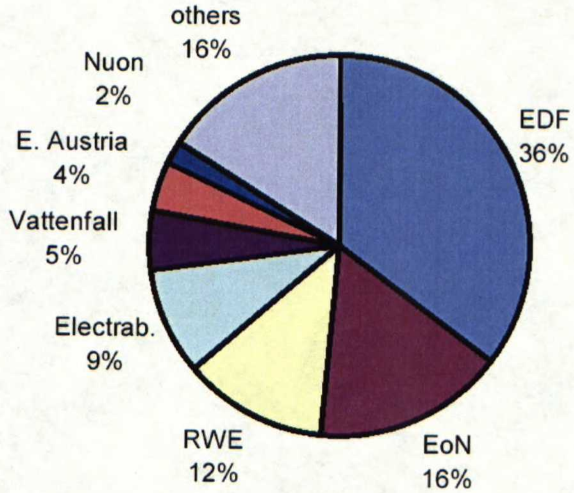

Figure 8. Market shares in a market area consisting of France, Germany, Austria and the Benelux countries. (Source: EU 2004, p. 3)

It can be seen that the largest players' market shares would be reduced as a result of electricity market integration. While the largest players, when considering the countries separately, dominated the market with market shares of up to 90%, the largest player, when considering the area as a single market, would have a market share of 36%. In addition, the aggregated market share of the largest players' is reduced, which lessens the oligopolistic characteristics of the market.

The change from monopolistic, regulated markets to competitive, deregulated markets may bring challenges to the firms in the sector. These challenges are discussed by Dyner and Larsen (2001). They claim that the firms will face major problems, if they attempt to use the same planning methods under competition as they did under monopoly. They argue that while operations research tools were extremely useful in a stable, monopolistic world, where relatively little uncertainty was present, such "hard modeling approaches" may not be as suitable in a deregulated market characterized by uncertainty. As reasons for uncertainty brought by deregulation, they mention increased price fluctuations, reduced information as a result of competition, and the consumers' right to switch supplier.

4 Consumption patterns

4.1 Sectoral breakdown

Total Continental European (as defined in Section 1.2) electricity consumption in year 2000 was approximately 2000 TWh. Figure 9 gives an overview of how much each Continental European country consumed during that year. It can be seen that Germany and France were clearly the largest consumers, consuming roughly 500 and 400 TWh, respectively, while the large South European countries, Italy and Spain, consumed around 300 and 200 TWh, respectively, thereby being the third and fourth largest consumers. The remaining six countries consumed roughly 50–100 TWh each. (Eurelectric 2004, pp. 72–76)

Figure 10 gives an overview of how electricity consumption is divided between different sectors in each Continental European country. It can be seen that industry is clearly the largest single consumer, being responsible for around 40% of total electricity consumption in Continental Europe. Households and the service sector are the next largest consumers, each responsible for somewhat over 20% of total consumption. Network losses account for about 7 %, whereas transport and agriculture are relatively insignificant consumers.

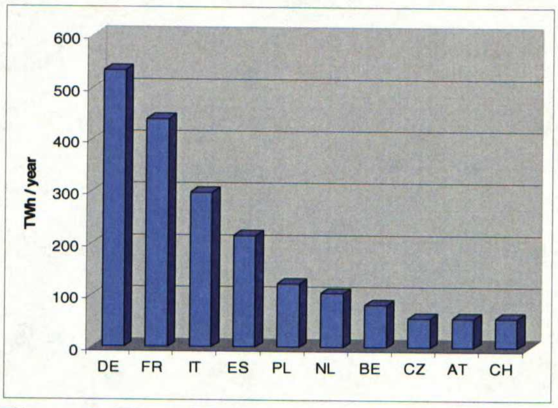

Figure 9. Electricity consumption in each Continental European country in year 2000.
(Data source: Eurelectric 2004, pp. 72–76)

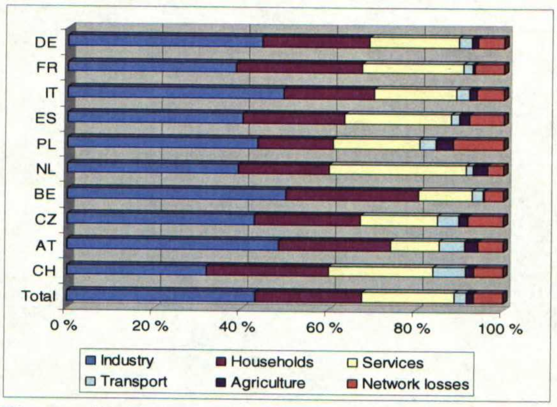

Figure 10. Proportional sectoral breakdown of electricity consumption in each country in year 2000.
(Data source: Eurelectric 2004, pp. 72–76)

It can also be seen that the structure of electricity consumption differs somewhat between the countries. For instance, the service sector in the Netherlands and the transport sector in Switzerland obtain particularly large proportions of electricity consumption in the respective countries. In contrast, the Swiss industry sector and the Austrian and Belgian service sector are relatively small consumers of electricity, compared to the same sectors in other countries. In Poland, network losses are relatively large, as they account for as much as 12 % of total Polish electricity consumption.

4.2 Yearly cycles

There are clearly discernable yearly cycles in Continental European electricity consumption. This section aims at describing the cycles, seeking similarities and differences between them, and explaining the factors that determine them. The analysis is based on average electricity consumption cycles, calculated as averages from consumption data of years 1998–2003, and scaled so as to make them comparable to each other[2]. The scaling has been done in such a way that the 100% level in the graphs corresponds to average consumption during the time period under view. The yearly cycles of the Continental European countries under view are depicted in the three graphs of Figure 11. Germany's yearly consumption cycle is drawn into each of these graphs in order to serve as a common reference.

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[2] The average electricity consumption cycles of each country are calculated from the expression $C(M)=\left(\frac{1}{6}\sum_{y=1998}^{2003}\frac{30c(y,M)}{d(y,M)}\right)\bigg/\left(\frac{1}{6\cdot 12}\sum_{y=1998}^{2003}\sum_{m=1}^{12}\frac{30c(y,m)}{d(y,m)}\right)$, where $C(M)$ represents average consumption in month M, $c(y,m)$ represents total consumption in month m of year y, and $d(y,m)$ represents the number of days in month m of year y. The values $c(y,m)$ are scaled by multiplying by 30 and dividing by $d(y,m)$ in order to remove the distortion caused by differences in the length of the months.

The consumption cycles' resemblance to each other is determined by visual inspection. The cycles are put into one of the three pictures according to how closely they follow the German consumption cycle. The first graph of Figure 11 contains the cycles that are closest to Germany's. These include the cycles of Belgium, Poland, Austria and Switzerland. The cycles that least resemble those of Germany, are those of Spain and Italy, which are depicted in the graph in the lower-right corner of Figure 11. The remaining countries' yearly consumption cycles resemble Germany's to some extent, and these are depicted in the remaining picture.

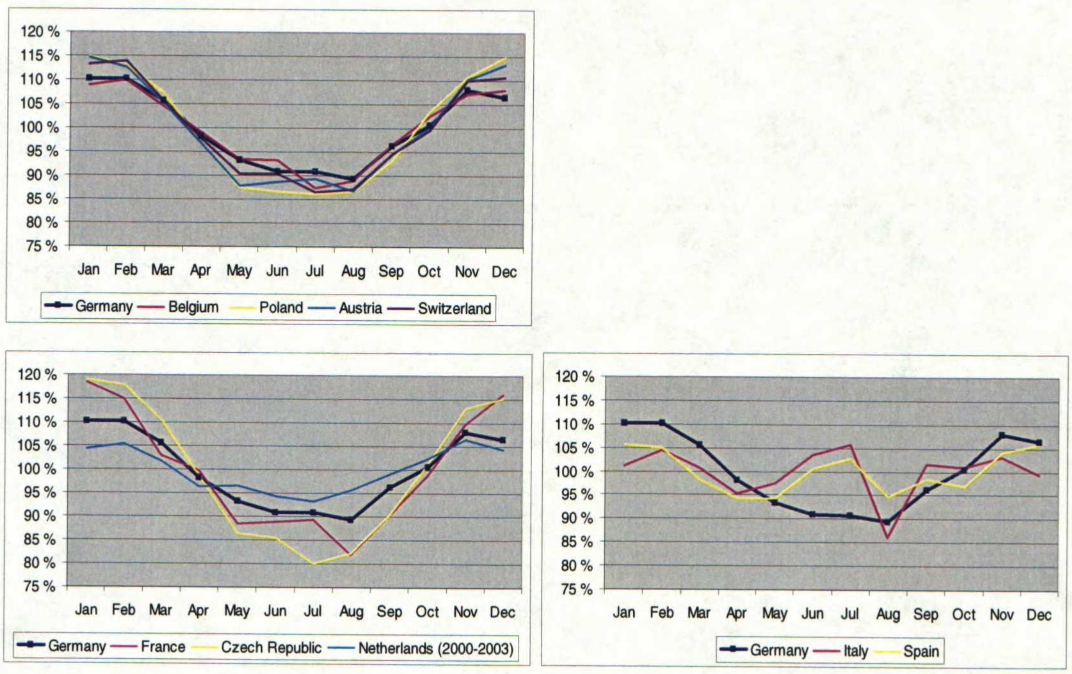

Figure 11. Average yearly cycles of electricity consumption. (Data source: UCTE[3])

The following observations can be made: All countries, except Spain and Italy, clearly exhibit U-formed yearly cycles, in which consumption is high in the winter and low in the summer. This form of cycles obviously is a result of an increased need for heating of homes and other premises in the winter. In the case of Spain and Italy, the consumption peak located in June and July can be explained by an increased need for air conditioning and the tourism season. The low level of consumption observed in August could be a result of Italians and Spaniards being on summer

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[3] The data concerning the Netherlands is obtained from PIRA Energy Group.

vacation. The temporarily reduced workforce would then result in a downward adjustment of production, and thus less consumption of electricity. In Spain, however the drop in August is not as clearly discernable as in Italy, where electricity consumption falls from its year-high in July to its year-low in August.

It can also be observed, that there are differences in the amplitudes of the yearly cycles. The amplitudes of the yearly cycles are largest in the Czech Republic and France, and smallest in the Netherlands. The Polish, Austrian and Swiss cycles also have amplitudes somewhat larger than average. In Italy and Spain, the yearly variation is low, but these countries do not exhibit the same type of yearly cycles, that can be observed in the other countries. Germany and Belgium follow cycles, which are relatively similar to each other and have amplitudes of roughly average size. One reason to the variation in cycle amplitudes may be the different climates: continental climates typically exhibit larger variation in temperature than coast climates. The larger-than-average amplitude of the consumption cycles of the Central and East European regions may be explained as resulting from the continental climate, while the low-amplitude cycle of the Netherlands may be explained with the coastal climate. It is, however, difficult to explain the very large amplitude of the French cycle with a continental climate, as France borders to both the Atlantic Ocean and the Mediterranean Sea.

In addition to seasonal changes in the Weather, there are other things as well that can affect electricity consumption. Special dates, such as public holidays, traditions, and other events will have some impact on electricity consumption. For example, during the Christmas holidays, electricity consumption tends to be low, because the industry and service sector consume much less. Also temporary changes in the weather may have a large influence on electricity consumption, since the need for heating or air conditioning depends on the temperature. In the long term, also changes in economic activity, i.e., economic fluctuation will influence the demand for electricity, as, e.g., industrial activity tends to remain lower or grow slower during economic recessions. In the long run, electricity consumption is also influenced by economic growth, changing trends of consumption, and the introduction of new technologies.

4.3 Daily cycles

Hourly consumption data is not available for all days. For the countries considered, it can only be obtained for the 3rd Wednesday of each month. The analysis of daily electricity consumption cycles is based on average cycles, calculated as averages for each hour, using consumption data from the 3rd Wednesdays of each month during year 2003. The average cycles are depicted in Figure 12. They have been scaled in such a way that the 100% level in the graphs corresponds to average consumption.

Again, the German cycle is used as a common reference, and is therefore included in every graph. The time scale at the bottom of the graphs refers to the exact instant of time, when the electricity consumption is measured, e.g., the value at the horizontal category "3" refers to average consumption at 3:00 a.m. It should be noted, that the observations that can be made from the graph only apply to working days, since the graphs are based exclusively on consumption data from Wednesdays.

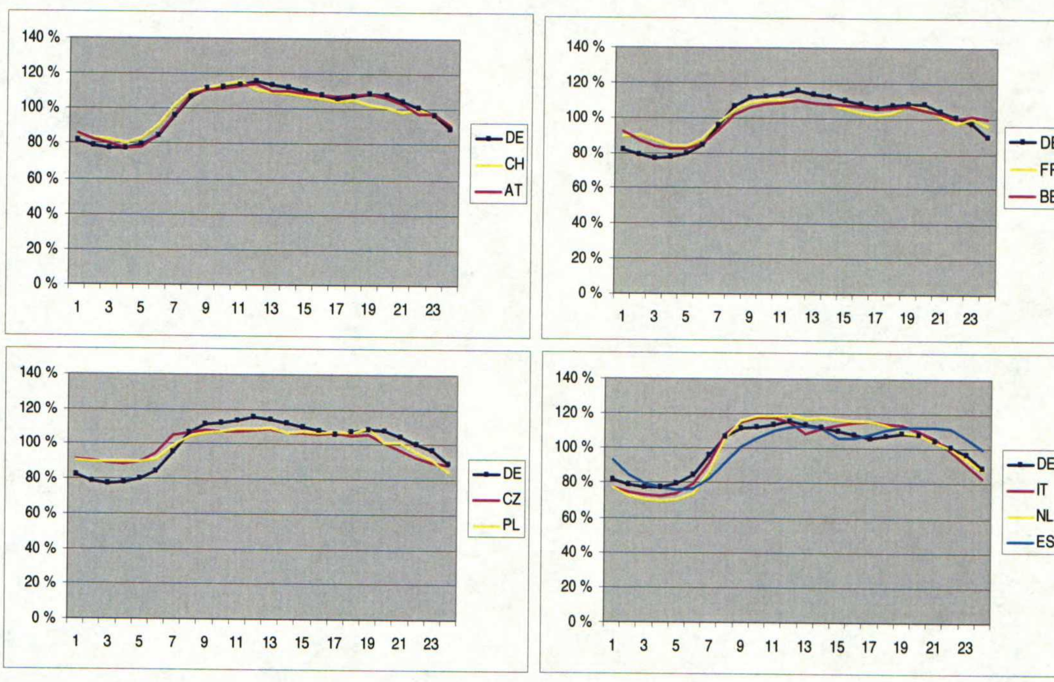

Figure 12. Average daily cycles of electricity consumption on working days. (Data source: UCTE) [4]

Some observations can be made by looking at the average daily cycles of electricity consumption. First of all, it can be seen that many of the cycles resemble each other to a large

[4] All countries considered belong to the Central European Time zone (GMT+1).

extent. For example, Germany and Austria have almost identical cycles, and Switzerland, France and Belgium have cycles that only slightly differ from the German cycles. The rest of the cycles are somewhat more different from the German cycle, but even these follow the same general form, the typical cycle being at its lowest in the night/early morning (around 3–5 a.m.), highest during noon (10–12 a.m.), and having another, smaller peak in the evening (7–8 p.m.). By observing the cycles of individual countries, the following observations can be made: France and Belgium differ from Germany in that the dispersion in their daily cycle is somewhat smaller than in Germany. Switzerland's particularity is that it seems to lack the evening peak altogether. The cycles of the Czech Republic and Poland have daily dispersions significantly flatter than those of Germany, and consumption is characterized by two almost flat parts: one during night-time (around 1–6 a.m) and another during daytime (around 8.a.m.–7 p.m.). The daily consumption cycles of Italy and the Netherlands have a dispersion that is somewhat larger than that of Germany. Also, it appears that the Netherlands do not have an evening peak, and in Italy the evening peak is earlier than in other countries, being as early as 5 p.m. The Spanish daily consumption cycle appears to be delayed by roughly two hours, compared to the cycles of the other countries. This can be interpreted as reflecting the late day-rhythm, where, e.g., dining takes place relatively late in the evening.

4.4 Growth

There is a connection between the growth of gross domestic product (GDP) of a country and the growth of electricity consumption in that country, as growth in the industry and service sector results in increased electricity consumption, as well as a growing GDP. A statistical connection between these entities can be observed in Continental Europe. Figure 13 shows the yearly average GDP growth rates and electricity consumption growth rates of the Continental European countries during 1990–2002.

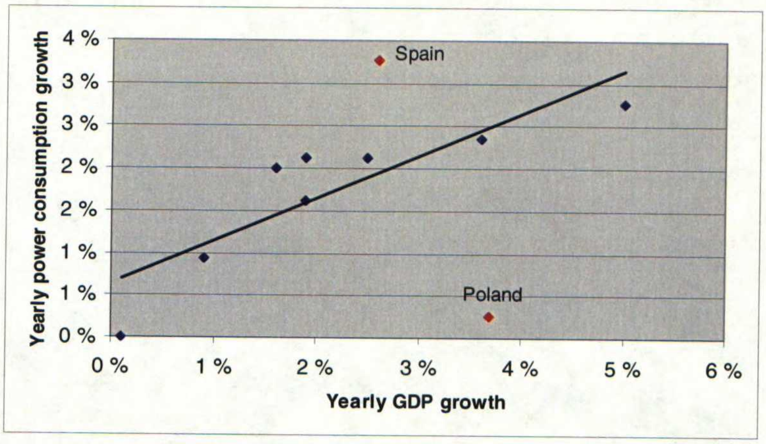

Figure 13. Correlation between average yearly growth rates of GDP and of electricity consumption[5] during 1990–2000. Spain and Poland are not accounted for in the linear regression line. (Data source: Eurelectric 2004, pp. 4, 64–70)

Most of the observations of Figure 13 lie relatively close to the linear regression line, which indicates a relationship between the two average growth rates. Spain and Poland, however, are situated far from the trend line. The Polish yearly growth rate of electricity consumption is very low, with respect to the yearly GDP growth rate, whereas the opposite applies to Spain, where electricity consumption growth rates have been very high. One explanation for the high growth rates of Spanish electricity consumption could be that Spain is experiencing growth in the use of electric appliances, e.g., air conditioning. The low growth rates of Polish electricity consumption may be a result of growth taking place mainly in the non-power-intensive sectors of the economy. Improvements in energy efficiency may also have reduced the consumption growth rates observed in Poland. If Poland and Spain are removed from the observations, the Pearson correlation coefficient between the yearly growth rates of GDP and of electricity consumption is 0.87. The trend line indicates that on average a 1% increase in the GDP growth rate is associated with a 0.5% increase in electricity consumption.

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[5] The average yearly growth rate g of electricity consumption can be solved from the expression $C_{2000} = C_{1990}(1+g)^{2000-1990}$, where C_{1990} and C_{2000} represent consumption in 1990 and 2000, respectively.

5 Production patterns

5.1 Structure

Figure 14 shows the production structure of the Continental European countries. Thermal[6] and nuclear power dominate, with 50.1% and 34.8% of total generation, respectively. The share of hydro power is 12.0%, while other renewables account for 2.5% of total generation. Other renewables include sources of power such as wind, solar, geothermal and biomass. Wind power accounted for roughly 50% of renewable generation in Continental Europe in 2002 and its share has been steadily increasing[7]. There is also a small portion of generation for which the power source is not specified in the statistics used, but this accounts for only about 0.6% of total generation in Continental Europe. (Eurelectric 2004, pp.163–187)

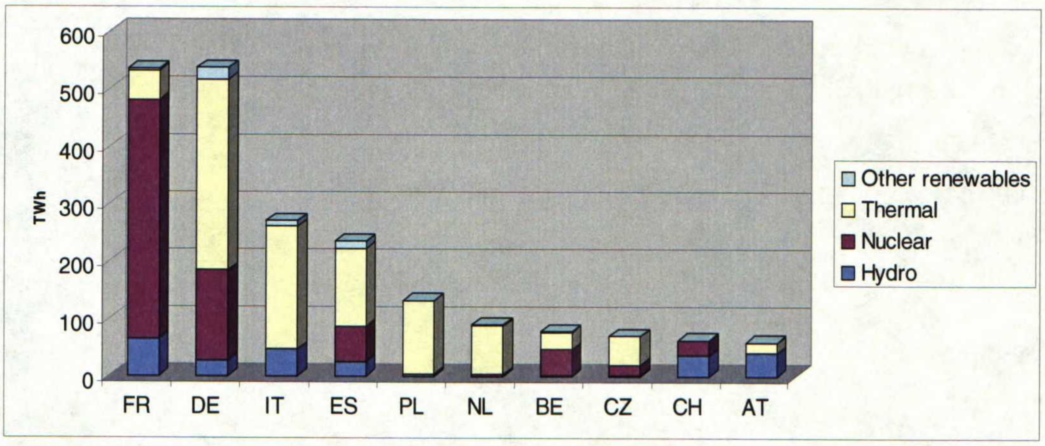

Figure 14. Production structure 2002. (Data source: Eurelectric 2004, pp. 163–187)

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[6] In this Thesis the term "thermal" power refers to conventional thermal power, i.e., it does not include nuclear power.

[7] Wind power tends to cause problems in the power networks, since the volatility of wind power generation is high. This increases the difficulty of equating the volumes generated and consumed in the electrical network. Since the share of wind power of total generation is increasing, its volatility may cause even more problems in the future.

The instantaneous supply curve of electricity is called the *merit order curve*. It illustrates the volume that would be generated at each price of electricity, thereby representing the cost structure of generation. Since different forms of generation have different marginal costs, the merit order curve consists of a number of "steps", or segments, representing different forms of generation. A hypothetical European (EU15) merit order curve is displayed in Figure 15. The other forms of generation than hydro, nuclear and wind are usually categorized under "thermal" power in this Thesis. The equilibrium price and quantity are determined at the intersection point of the demand curve and the merit order curve. The equilibrium also determines the forms of generation that are used: the segments of the merit order curve located to the left of the intersection point represent the forms of generation in use. In the figure, the forms of generation in use depend on where the demand curve is located: If, for instance, the supply-demand equilibrium lies on the "coal" segment of the merit order curve, the framework implies that hydro, wind, nuclear power as well as thermal power fueled by coal are used for generation. Similarly, if the intersection point lies on the segment "gas turbine", three more forms of generation are taken into use, in addition to hydro, wind, nuclear and coal.

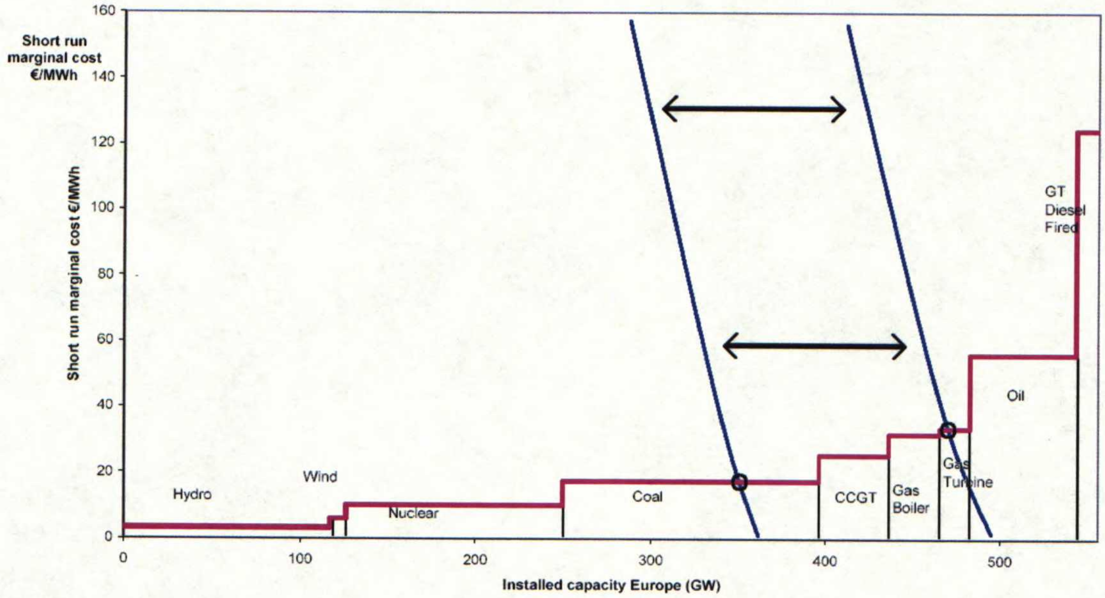
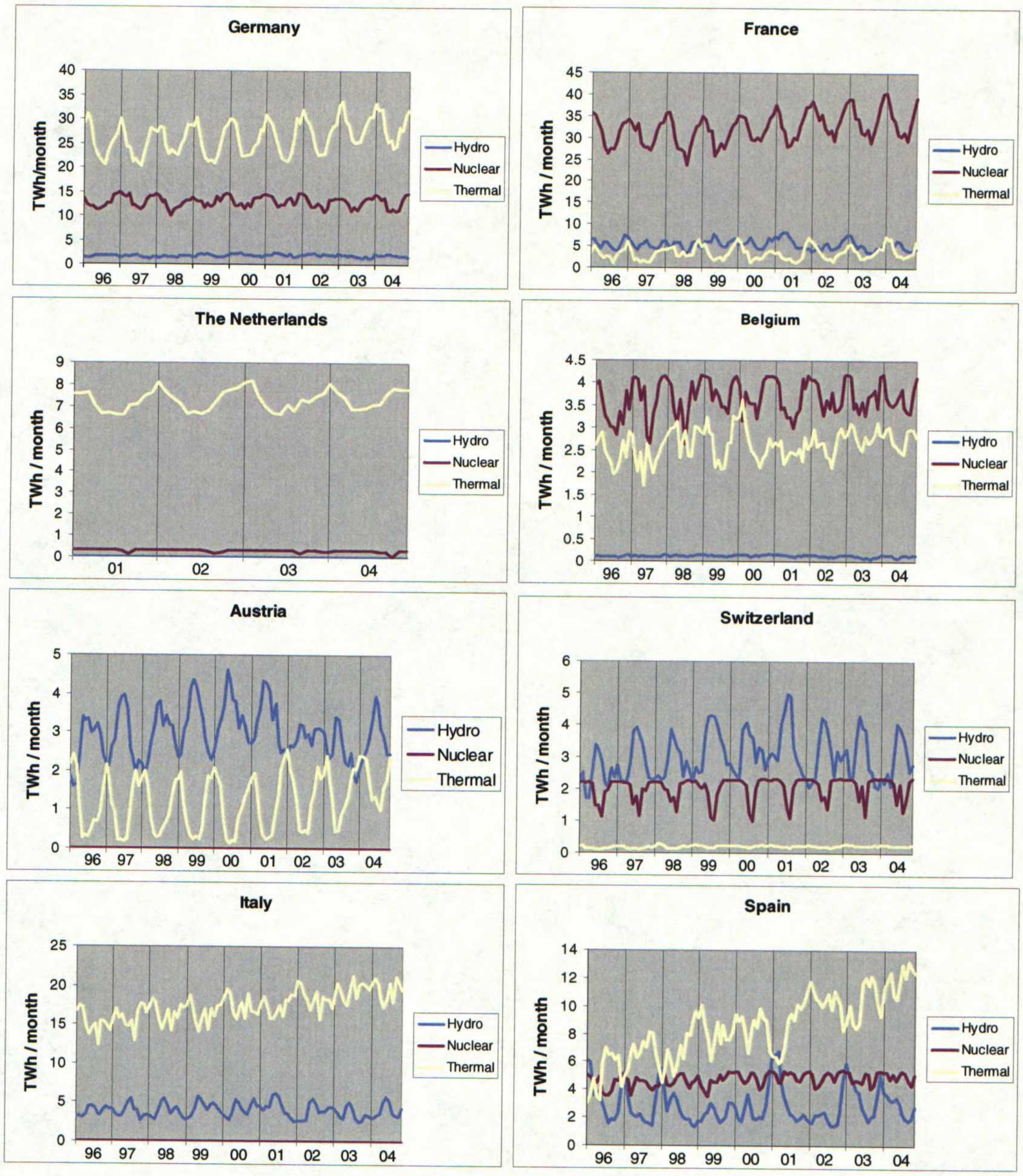


Figure 15. A hypothetical European merit order curve (the rising curve) and demand curve. The merit order curve is based on the total installed capacity of the EU15. (Edited from: IEA 2003, p. 19)

There are many factors that may affect the costs and available volumes of generation represented by the merit order curve. These factors include, for example, the availability and price of fuels, such as coal, gas and oil. The price of greenhouse gas emissions also increases the marginal costs of certain forms of generation (Emissions trading is discussed in more detail in Section 5.3). The weather is a very important determinant of the volumes of hydro and wind power generation. The maintenance of power plants (nuclear and thermal plants, in particular) also affects the volumes that can be generated. It should be noted, however, that the merit order curve does not in all cases perfectly represent the costs of generation. Because of the poor adjustability of nuclear and thermal generation, these forms of generation cannot easily be adjusted up or down in response to quick variations in demand and price. Therefore, the generators may be forced to generate in the night even if prices were lower than the costs of generation.

5.2 Yearly cycles of the production structure

The yearly variation of the production structure in the countries under view can be observed in Figure 16. For each country, the monthly production data is plotted as three time-series, which exhibit the variation in the three forms of generation. Since statistics show monthly data only for hydro, nuclear and thermal generation, other forms of generation are excluded here.


Germany
TWh/month
0
5
10
15
20
25
30
35
40
96 97 98 99 00 01 02 03 04
Hydro
Nuclear
Thermal
France
TWh / month
0
5
10
15
20
25
30
35
40
45
96 97 98 99 00 01 02 03 04
Hydro
Nuclear
Thermal
The Netherlands
TWh / month
0
1
2
3
4
5
6
7
8
9
01 02 03 04
Hydro
Nuclear
Thermal
Belgium
TWh / month
0
0.5
1
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3
3.5
4
4.5
96 97 98 99 00 01 02 03 04
Hydro
Nuclear
Thermal
Austria
TWh / month
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96 97 98 99 00 01 02 03 04
Hydro
Nuclear
Thermal
Switzerland
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96 97 98 99 00 01 02 03 04
Hydro
Nuclear
Thermal
Italy
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96 97 98 99 00 01 02 03 04
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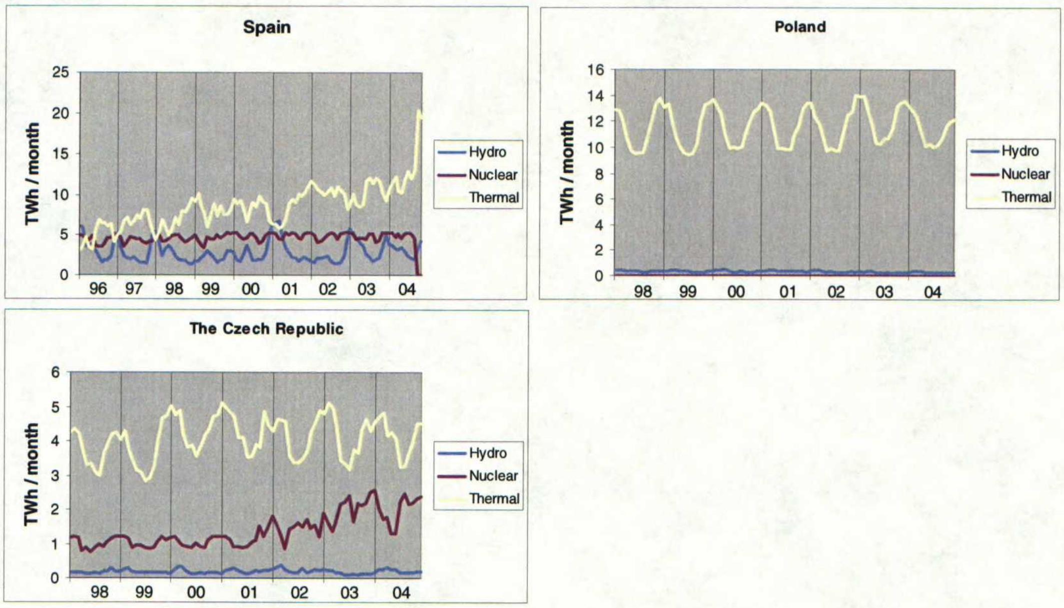

Figure 16. Long-term variation of the production structure. (Data source: UCTE)

Hydro generation is influenced by the inflows of water in the reservoirs and thus also by the hydrological characteristics of each season. If the size of the reservoirs were not limited, water could be stored during seasons of high inflows or low demand for use during seasons of low inflows or high demand. However, because reservoirs have limited volumes, hydro generation depends on the inflows during the respective seasons. Inflows are low in the winter, when much of the precipitation is in the form of snow. In the summer, inflows are high, as the snow in the Alps melts and the rain falls down as water, thereby reaching the reservoirs in a relatively short time. Because of seasonal differences in inflow volumes, hydro generation is adjusted up in the summer, when inflows are high, and down in the winter, when inflows are low. If there were no restrictions on the capacity of the reservoirs, it would be profitable to store water in them during the summer, when inflows are high and demand for electricity is relatively low, and use it for generation in the winter, when inflows are low and demand is relatively high. However, limitations on reservoir capacity and increased inflows force generators to increase hydro generation in the summer despite the lower demand. The yearly cycle of water power, in which generation is high in the summer and low in the winter, can be discerned at least in Switzerland and Austria, and, with some difficulty, in Italy. In the other countries, such yearly cycles are not visible.

Nuclear and thermal generation are independent of the season and are therefore used to generate the remaining part of the electricity demanded. In the summer, thermal generation is adjusted down because hydro generation volumes are particularly large and demand is low. Nuclear and thermal power plants also have to undergo yearly maintenance, which is usually carried out during the summer, when the large supply of hydro generation and the low demand for electricity make maintenance less costly in terms of lost revenue.

5.3 Emissions trading

The Kyoto protocol is an international attempt to reduce global greenhouse gas emissions. The Kyoto Protocol, approved by the EU in 2002 (Council Decision 2002/358/EC), commits the EU to reduce its emissions of greenhouse gases by 8% from the level of 1990 during 2008–2012. Directive 2003/87/EC of the European Parliament and of the Council establishes a scheme for greenhouse gas emissions trading within the EU. The directive aims "to contribute to fulfilling the commitments of the European Community [...] more effectively, through an efficient European market for green house gas emission allowances, with the least possible diminution of economic development and employment". (EU 2003c, p. 32)

One greenhouse gas emission allowance gives the right to emit one tonne of carbon dioxide equivalent during a specified period. Since the allowances can be traded, there exists a market price for them (often called "carbon price"). The price of the required allowances increases the marginal costs of power generation. The increase in marginal costs can be expressed as an upward shift in those parts of the merit order curve, which represent generation involving greenhouse gas emissions. The magnitude of the upward shift of each part of the curve depends on the cost of the greenhouse gas emissions resulting from the respective form of generation. The upward shift results in an increase in the electricity prices in the member states of the European Union.

Figure 17 illustrates, how a carbon price of 20€ per CO_2 tonne would shift up parts of a hypothetical European merit order curve. It can be seen in the figure, that the carbon price has no effect on the marginal costs of hydro, wind and nuclear generation, which do not involve greenhouse gas emissions, while the marginal costs of other forms of generation increase. The largest impact is on the marginal costs of coal-fired generation. The parts of the merit order curve that are affected by the carbon price represent forms of generation categorized under "thermal" power in this Thesis. The realized carbon prices during the first four months of 2005 are plotted in Figure 18.

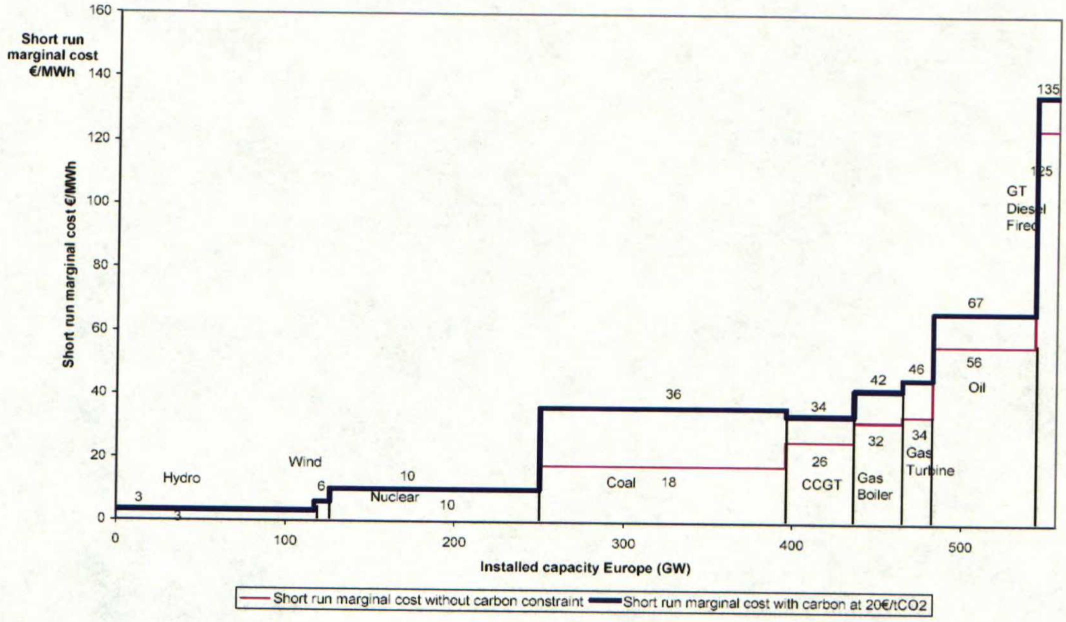

Figure 17. Impact of a carbon price of 20 € per CO_2 tonne on a hypothetical European merit order curve. The merit order curve is based on the total installed capacity of the EU15. (Source: IEA 2003, p. 19)

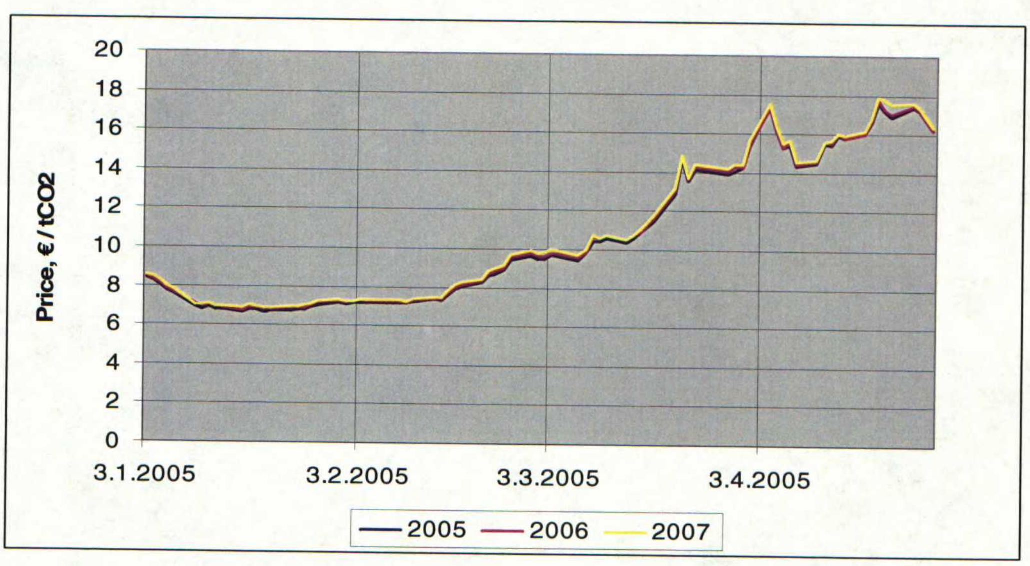

Figure 18. Carbon price development during January–April 2005. The labels 2005, 2006 and 2007 refer to the year that the allowance concerns. (Data source: Point Carbon)

6 Transmission patterns

6.1 Main directions of transmission

The largest electricity flows between the countries considered in this Thesis are depicted in Figure 19. The figure also shows the flows in opposite directions associated with the largest flows. The sizes of the flows will change from year to year, and their order may be different in another year, but only somewhat different. Therefore the transmission data from year 2003 will be sufficient to give a picture of the magnitudes of the flows relative to each other.

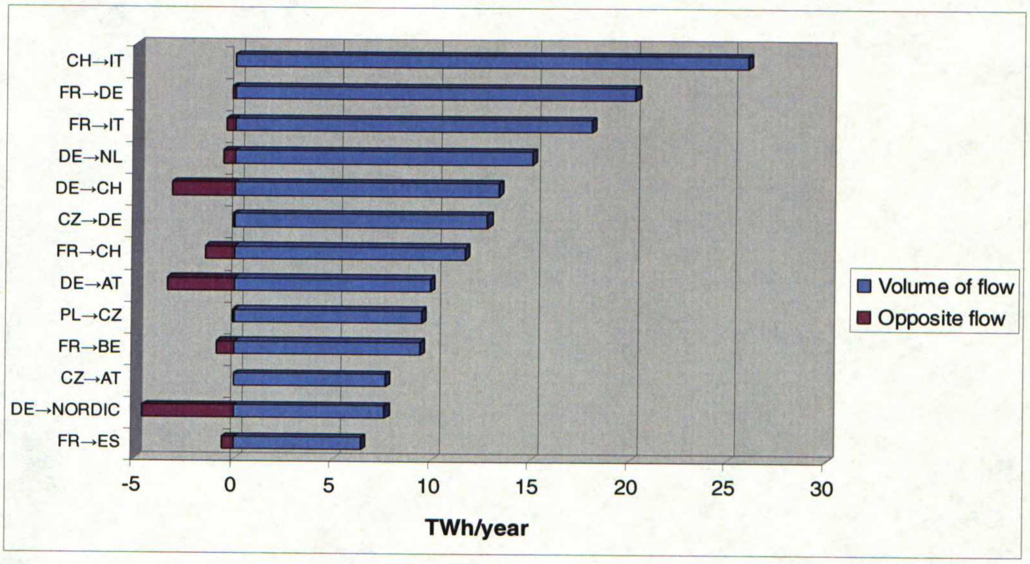

Figure 19. The largest total electricity flows during year 2003 and the total flows in directions opposite to those. (Data source: UCTE)

It can be observed in the figure that there are sizable opposite flows associated with some of the electricity flows. During the year, electricity may flow in one direction part of the time and in the other direction the rest of the time. Electricity may, for example, flow in one direction during daytime, and in the other direction during night-time. Similarly, the main direction of a flow may depend on the time of year. Such time-variation of transmission will be considered in the following sections.

Another thing that should be noted in Figure 19 is the fact that the general directions of the flows do not vary much during the year in most cases. Significant opposite flows can be observed only in few cases: transmission between Germany and Nordic, where the yearly flows are roughly equal in both directions and in transmission from Germany to Austria and to Switzerland, where the sizes of the respective opposite flows are around 20–30% compared to the flow in the general direction. The largest flows are depicted in Figure 20, which is based on yearly net flows. The figure also shows whether the country is a net exporter or importer, and how large the country's surplus or deficit is as a percentage of consumption. There are also a number of smaller electricity flows of some significance to the countries involved that have not been considered in the picture. Such flows exist, e.g., between Belgium and the Netherlands and between France and the United Kingdom. For clarity, such flows have been left out from the picture and only the most significant cross-border flows are considered. Transmission between continental Europe and the Nordic countries is considered in the research, because of its significant size, even though other aspects of the Nordic countries, such as their fundamentals, are excluded from the research.

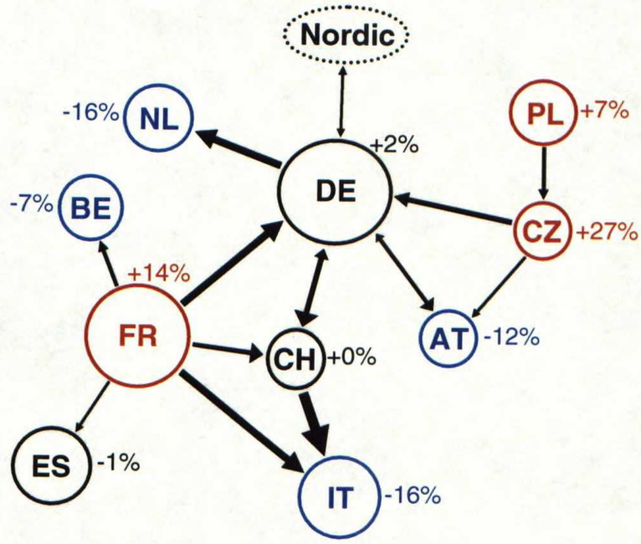

Figure 20. The general direction of electricity flows and each country's total net exports of electricity in 2003 as a share of national electricity consumption. Red and blue circles are used to indicate, whether the country is a net exporter or importer, respectively. (Data source: UCTE)

Figure 21 illustrates the amount of total electricity flows that has been excluded from the research. The bar on the right in the figure shows the amount of terawatt hours excluded and includes all flows that have taken place between one of the ten Continental European countries considered in the research and another country not considered in the research (excluding Nordic countries). In contrast, the bar on the left in the figure shows the electricity flows that are considered in this research. This includes the flows between the ten Continental European countries considered and the flows between these ten countries and the Nordic countries. It should be noted, that the figure concerns all flows where one of the counterparts is one of the ten Continental European countries considered, i.e., the figure considers total flows in all directions, not just, e.g., net flows.

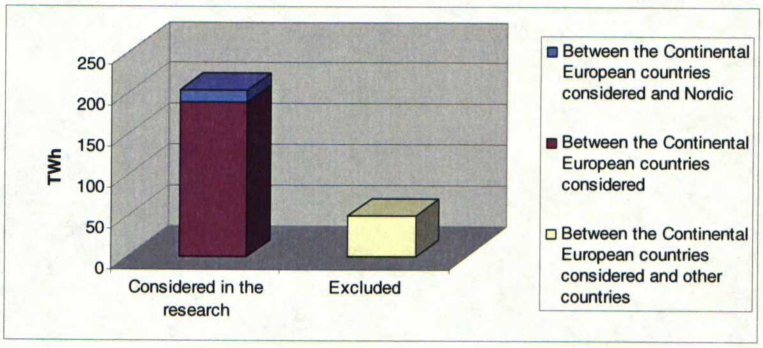

Figure 21. Total electricity flows excluded from the research, according to data from 2003. (Data source: UCTE)

It can be seen in Figure 21 that a sizable amount of transmission is left out from the research. However, the sizes of these individual flows are quite small, even though they add up to form a large sum. Therefore they are individually less significant from a big picture perspective than the flows that are considered in the research.

6.2 Yearly cycles

Time-series of monthly net transmission between countries considered in this Thesis are plotted in Figure 22. The electricity flows considered in the figure are the ones considered in last section, i.e., the largest flows occurring between Continental European countries. It should be noted, that the figure only presents the monthly net flows. Instantaneous flows do not always occur in the direction of the monthly net flows.

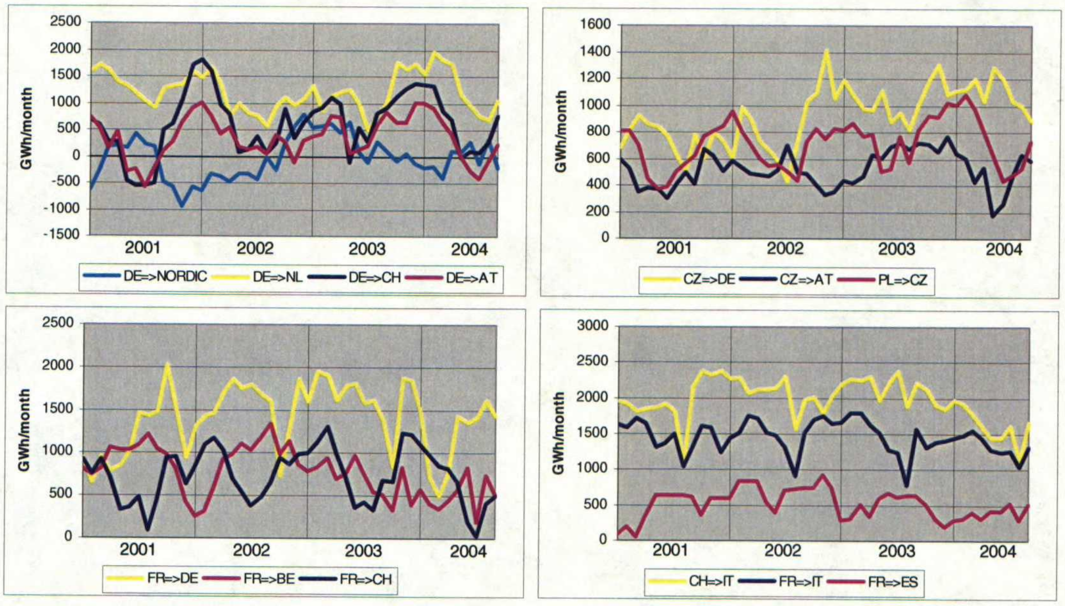

Figure 22. Monthly net transmission time-series during 2001–2004. (Data source: UCTE)

It can be seen in Figure 22, that some of the time-series exhibit yearly cycles, whereas no regular patterns can be discerned in others. The most common (and easiest to spot) form of yearly variation is a pattern in which the transmitted volume (and possibly the direction of transmission) varies between summer and winter. In some cases, the yearly cycle can only be determined with low reliability. Table 2 presents the results of an analysis based on the time series plotted in Figure 22.

Table 2. Analysis of the yearly cycles in transmission.

Electricity flow	Observation
Germany → The Netherlands	High in the winter, low in the summer
Germany → Switzerland	High in the winter, low/reversed in the summer
Germany → Austria	High in the winter, low/reversed in the summer
Germany → Nordic	–
Poland → The Czech Republic	High in the winter, low in the summer
The Czech Republic → Germany	High in the winter, low in the summer
The Czech Republic → Austria	–
France → Germany	–
France → Belgium	–
France → Switzerland	High in the winter, low in the summer
France → Italy	Low in August
France → Spain	–
Switzerland → Italy	Low in August

6.3 Daily cycles

Time-series depicting day and night transmission are plotted in Figure 23. The only data that could be obtained was instantaneous transmission at 3.00 a.m. in the night and 11.00 am in the day, for the third Wednesday of each month. However, since Wednesday can be considered a typical working day, and data is available for a time-span of several years, conclusions can be made, based on the time-series, about electricity flows during day and night-time on a typical working day. The conclusions may, however, not correctly portray transmission during weekends.

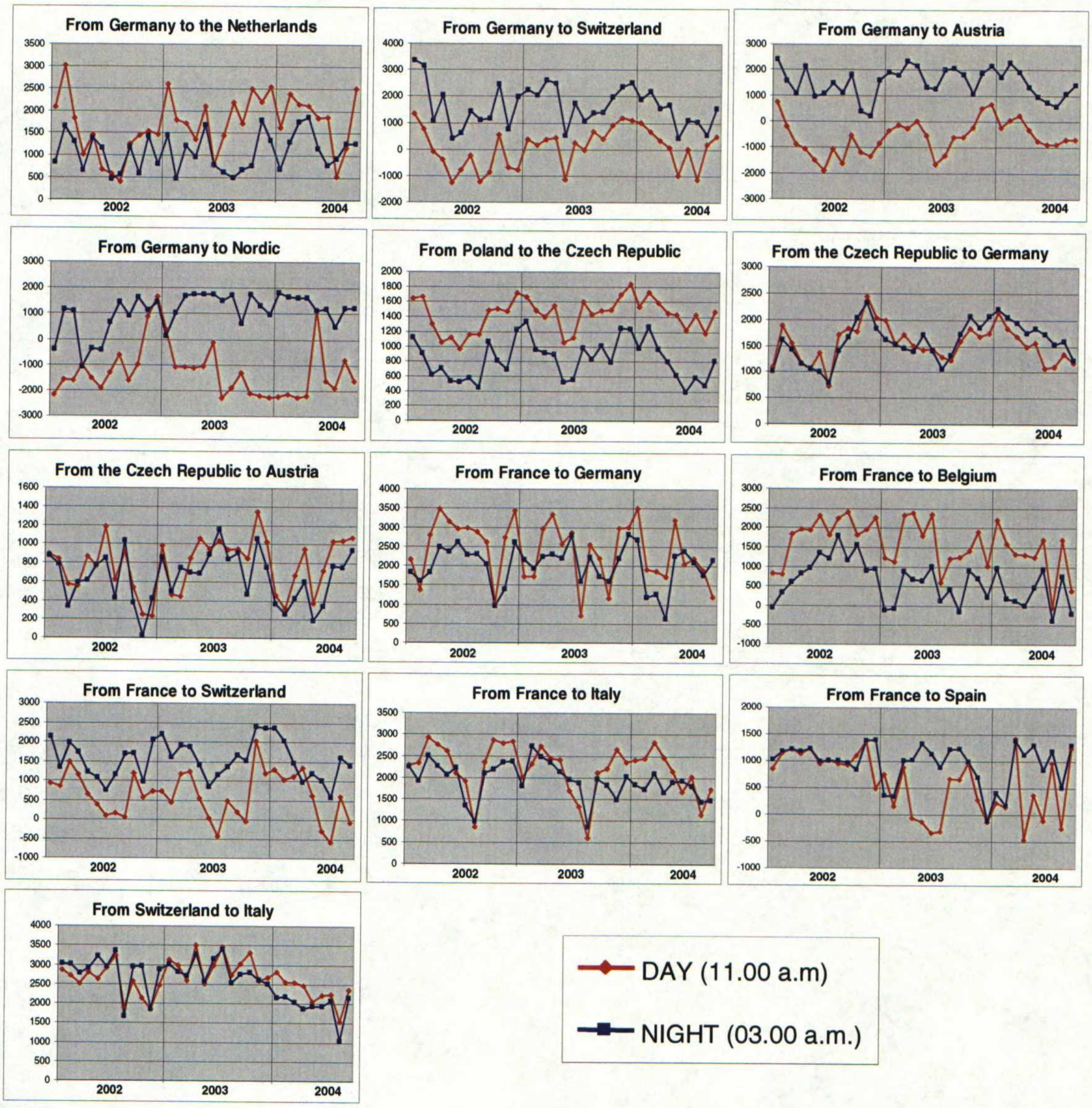

Figure 23. Cross-border transmission (in MWs) during daytime (11.00 a.m.) and night-time (3.00 a.m.). (Data source: UCTE)

It can be seen in Figure 23, that in many cases either the time-series representing transmission in the daytime or the one representing transmission in the night is above the other one most of the time. These observations imply that transmission in the direction considered is intensifying either during daytime or night-time. In some cases even the direction of transmission appears to vary between day and night. The day-night transmission pattern does not, however, appear to depend much on the time of year, i.e., flows are intensified during the same time of day regardless of the season considered. Table 3 presents the results of an analysis based on the time series plotted in Figure 23. In some cases, the daily cycle can only be determined with low reliability

Table 3. Analysis of the daily cycles in transmission.

Electricity flow	**Observation**
Germany → The Netherlands	Low in the night
Germany → Switzerland	Reversed in the daytime
Germany → Austria	Reversed in the daytime
Germany → Nordic	Reversed in the daytime
Poland → The Czech Republic	Low in the night
The Czech Republic → Germany	–
The Czech Republic → Austria	–
France → Germany	Low in the night
France → Belgium	Low in the night
France → Switzerland	Low in the daytime
France → Italy	Low in the night
France → Spain	Low in the daytime
Switzerland → Italy	–

6.4 Summary of transmission patterns

The results of the analyses of yearly and daily cycles in electricity transmission are summarized in Figure 24. The figure categorizes each cross-border electricity flow according to when transmission in the direction of the respective arrow is intensified.

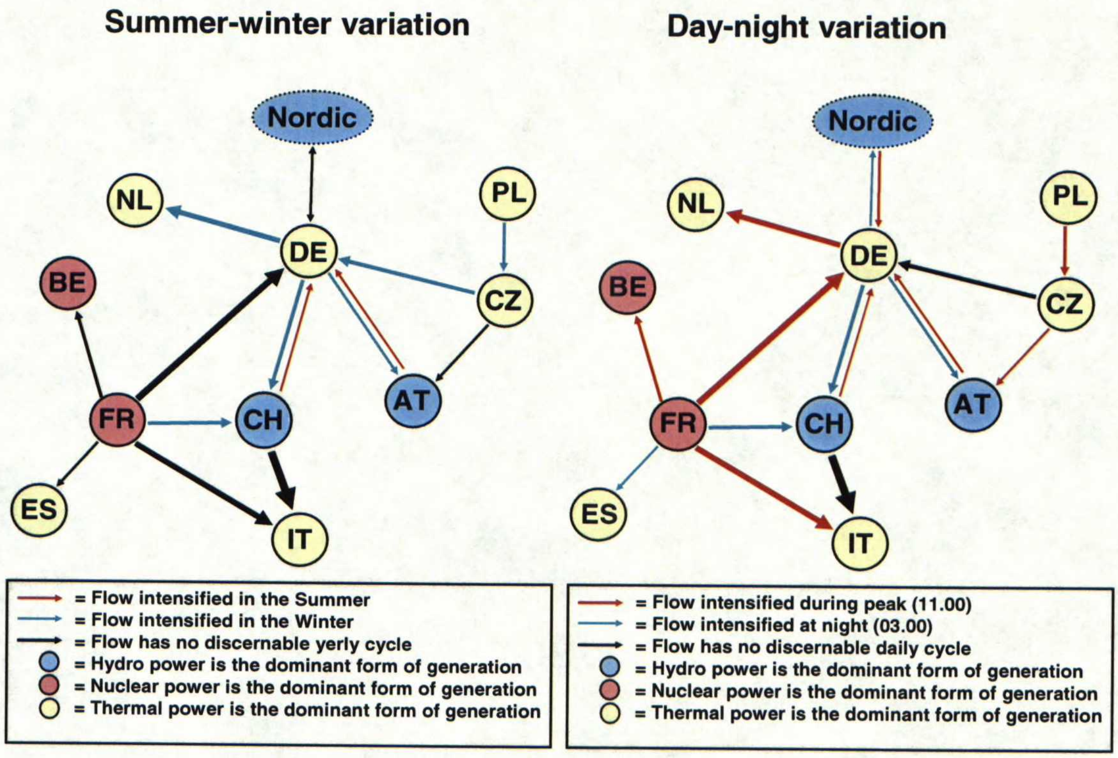

Figure 24. Transmission patterns in Continental Europe.

Comparing the yearly cycles in cross-border electricity transmission observable in the left diagram of Figure 24 to the general directions of the electricity flows presented in Figure 20 shows that winter apparently has the effect of intensifying flows in the direction of the long-term general direction of each flow. The reason for this is probably that countries which are net importers of electricity have an even greater need for imports in the winter, when there is an increased need for heating. It should, however, be noted, that there are also electricity flows where yearly cycles cannot be observed, as well as flows, which are not just smaller in the summer, but flow in an opposite direction in the summer than in the winter (in these cases two separate arrows, pointing in opposite directions, have been drawn to represent the flows in the summer and in the winter).

Another observation that can be made in the yearly cycles is that Switzerland and Austria tend to import large volumes during the winter, while they tend to import less, or even export during the summer. Whereas this observation is in accordance with the preceding observation of intensification of flows during the winter, it can also be interpreted as exhibiting the differences in the production structures of the countries: countries dominated by hydro power, such as Switzerland and Austria, have a greater need for imports in the winter than in the summer, because inflows are smaller in the winter than in the summer. As was noted in Chapter 5, limitations on reservoir capacity imply that more hydro generation has to be allocated to seasons of high inflows than to seasons of low inflows. This phenomenon can, however, not be observed in yearly transmission between Germany and the Nordic countries, even though hydro power is the dominant form of generation in the Nordic countries as well. One reason for this may be that the reservoirs in the Nordic countries are large enough to allow the saving of water from seasons of high inflows for seasons of low inflows.

It can also be observed, that the electricity flows from Germany and France toward Switzerland, Austria and the Nordic countries are intensified during night-time. The reason for this probably lies in the use of hydro power in Switzerland, Austria and the Nordic countries, while generation in Germany and France is mainly based on thermal and nuclear power. Since the generation of hydro power can be easily adjusted up or down, while thermal and nuclear power cannot be quickly adjusted, it is efficient and profitable for hydro power generators to produce and export hydro power during daytime, when demand and the price are high, and not generate so much during night-time, when demand and the price are low. The generators of thermal or nuclear power, however, cannot as easily make short-term adjustments in the volumes generated, and therefore, they have to produce during night as well, when electricity prices are low. Therefore, electricity is exported during night-time from thermal and nuclear power dominated countries to hydro power dominated countries.

In short, the observations that can be made by analyzing the daily and yearly cycles are the following: The daily transmission cycles can be explained by cycles in consumption together with differences in the countries' production structures. The yearly transmission cycles can be explained on one hand by cycles in consumption, and on the other hand by cycles in generation.

7 Analysis of market prices in Continental Europe

This chapter analyses price information in the Continental European electricity market. Countries are then clustered according to the price information, so that countries exhibiting price convergence are put in the same category. The German spot price is compared to that of other countries in Figure 25 and Figure 26, which depict the rolling 7-day average spot prices of 2004 in the Continental European countries that have power exchanges.

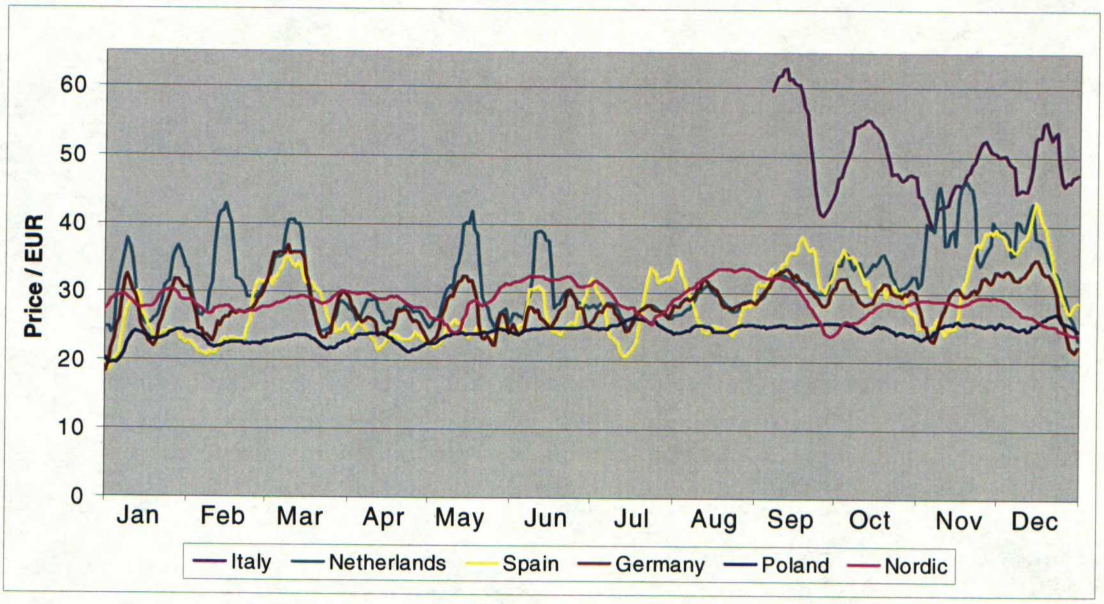

Figure 25. Rolling 7-day average spot price during 2004 in the countries that have power exchanges, excluding France and Austria. Italian price data begins in September 2004. (Data sources: APX, EEX, GME, Nord Pool, OMEL, PolPX)

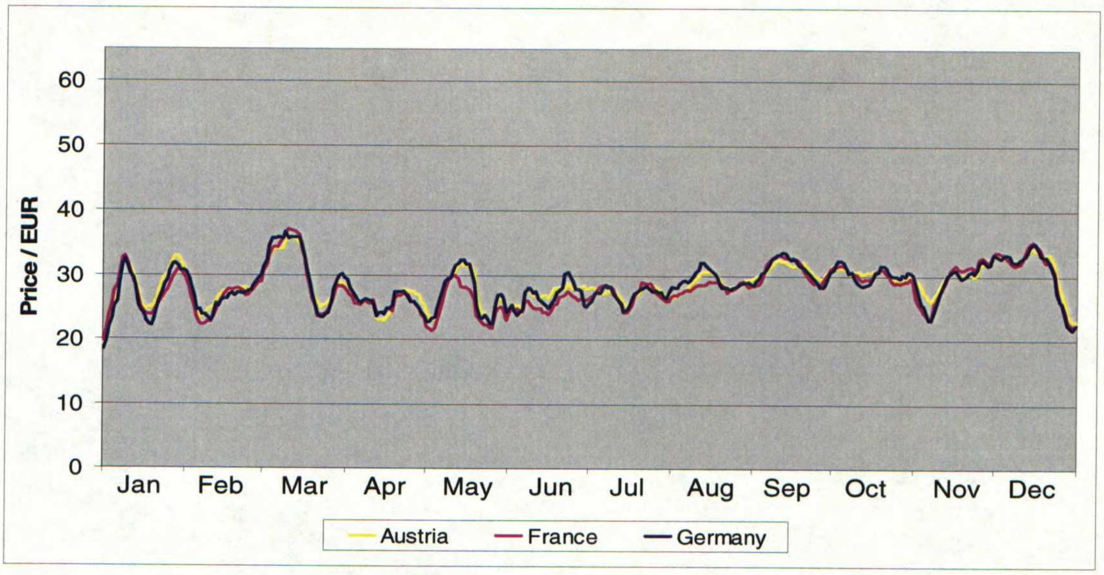

Figure 26. Rolling 7-day average spot price during 2004 in Germany, Austria and France. (Data sources: EEX, EXAA, Powernext)

It can be seen in Figure 26 that the 7-day rolling average spot price is almost equal in Germany, France and Austria, whereas Figure 25 shows that there are substantial price differences between the other countries, as well as between Germany and the other countries. This implies that the bottlenecks between these three countries are substantially less severe than those between other Continental European countries (of those that have power exchanges). However, taking a 7-day rolling average may smooth out peaks in the data. Therefore, in order to find out whether there are substantial short-term differences between the three prices, the daily average and hourly spot prices have to be studied. These have been depicted in Figure 27 and Figure 28, albeit not for the whole year 2004, since this would have made the graph messy. The inspected time periods have, however, been chosen so that they should be sufficient to form a picture of how well the prices have converged.

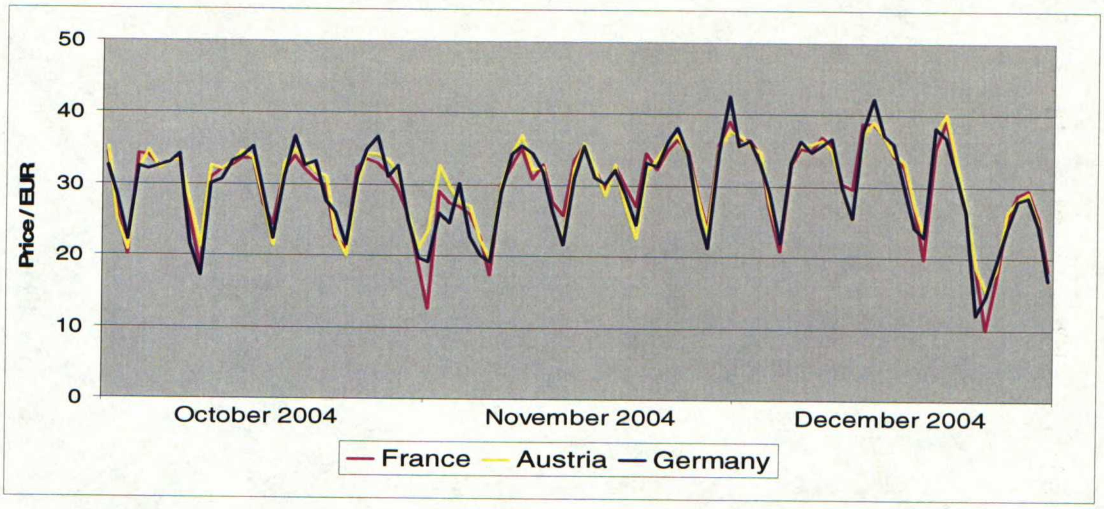

Figure 27. Daily average spot prices during the last quarter of 2004. (Data sources: EEX, EXAA, Powernext)

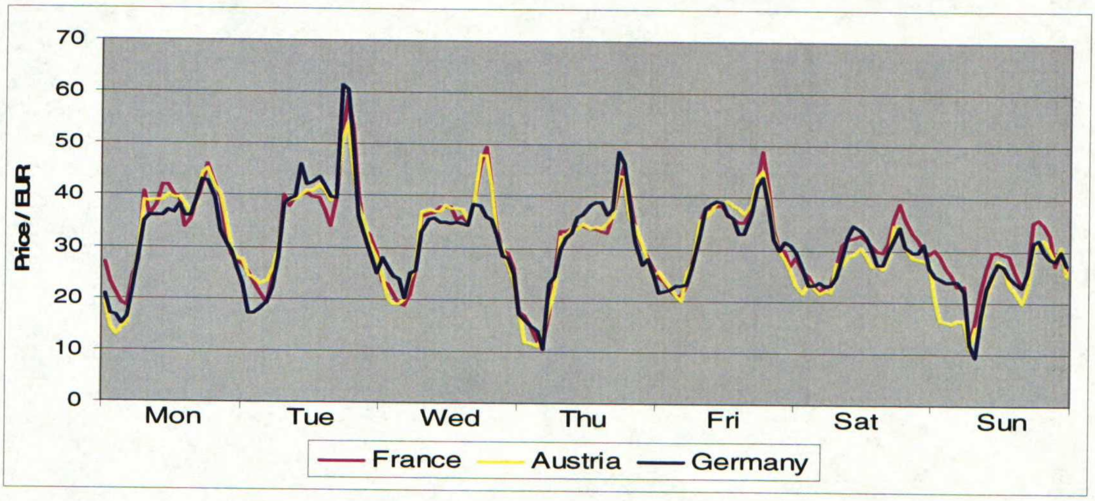

Figure 28. Hourly spot price during the third week of November 2004. (Data sources: EEX, EXAA, Powernext)

Only few deviations of substantial extent (several euros) can be observed in the daily average spot prices depicted in Figure 27. Since the time period considered is as much as three months long, and includes winter months as well as a holiday season (Christmas 2004), it should be a good indicator of convergence of daily average prices. In the case of hourly spot prices, illustrated in Figure 28, the differences are somewhat larger, but even the hourly prices appear to be very close to each other most of the time, even during the hours of the largest price peaks.

This implies that even the hourly prices are close to equal most of the time. The sample week in question can be considered a typical week, which improves the reliability of this statement.

Based on the price comparisons conducted above, it appears that the region formed by Germany, France and Austria can be considered as an area where the cross-border price differences are small, whereas they are large elsewhere in Continental Europe. Based on Chapter 2, this can be interpreted as meaning that transmission bottlenecks are not very severe between these three countries. Therefore, the area can be considered as a near-single-price region.

In Switzerland, there is no power exchange and therefore a single national price cannot be determined. However, some view of the price level in the country be extracted from price data on OTC (over-the-counter) contracts, i.e., contracts that do not involve power exchanges. An index of Swiss OTC peak hour (11–12 a.m.) prices has been compiled by Dow Jones. This index, called SWEP (Swiss Electricity Price Index), can be obtained from the websites of major Swiss energy companies, e.g., Atel.

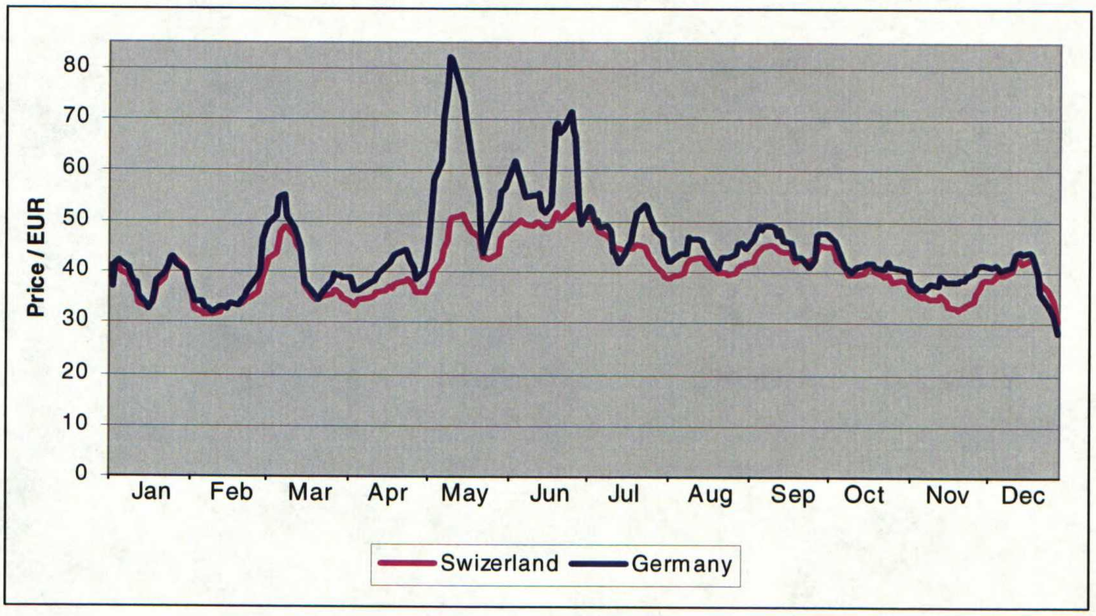

Figure 29. Rolling 7-day average peak hour (11–12 a.m.) prices of year 2004 in Switzerland and Germany. The Swiss price curve is based on the SWEP index reflecting OTC prices, whereas the German price curve is based on hourly spot prices in the German power exchange EEX. (Data Sources: EEX, Dow Jones)

The SWEP index results are plotted in Figure 29. It should be emphasized, that both the Swiss and German data used for the diagram are peak hour price data, i.e., they are likely to represent the highest prices of the respective days. The reason for using peak hour price data instead of daily average price data as in the other price comparisons is the fact that only peak hour price data could be obtained for Switzerland, whereas the spot price data of the German power exchange EEX could be obtained for any hour, including the peak hour 11–12 a.m.

According to the diagram, the difference between Swiss and German electricity price is small most of the time – clearly smaller than the price differences of Figure 25, but somewhat larger than those of Figure 26. The price difference appears to be relatively large, however, in May and June of 2004. It should be noted, however, that the price difference is likely to be higher during the peak hour than on average, since, as was observed in Chapter 6, cross-border trade is intensified during the hours of high demand. This puts pressure on transmission lines, which results in bottlenecks and thereby price differences between the countries. Therefore, the price difference is probably exaggerated in Figure 29, since it is only based on peak hour price data. It is thus likely, that the German and Swiss electricity prices are, in general, rather close to each other. Therefore, Switzerland should be regarded as being part of the near-single-price region to which Germany, France and Austria also belong. The analyses in Chapter 8 are based on the assumption that these four countries form a single-price region, which is here called Western Central Europe (WCE). Using one region simplifies the system under view, as most of the countries considered interact with the WCE region and do not interact much with each other. The resulting system is illustrated in Figure 30.

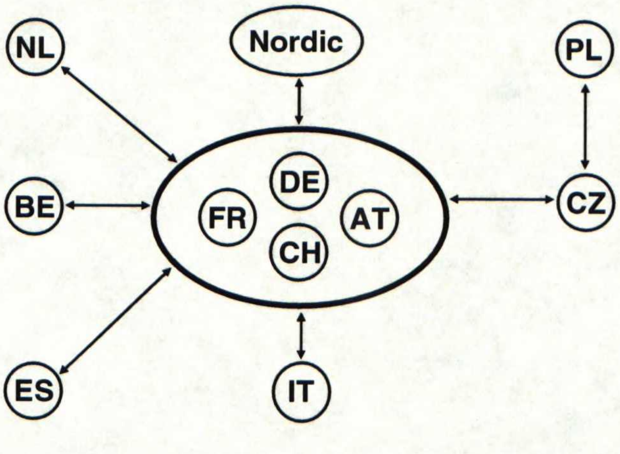

Figure 30. Western Central Europe as a single-price region.

Figure 1 in Chapter 1 illustrates the European Commission's view on potential regional electricity markets in the interim stage of the integration process. There is one difference between the West European market presented in Figure 1 and the Western Central European market presented in Figure 30: the interim-stage region proposed by the Commission includes the Benelux countries. However, presently the power price in the Netherlands differs significantly from that of France, Germany, Switzerland and Austria, while these four countries already form a near-single-price region. This implies, that in order for the Commission's plan regarding an interim-stage West European power market to realize, additional transmission capacity may be required for transmission between the Benelux countries and the other West European countries. Price convergence could also be furthered by improving the methods of congestion management, since this would improve the utilization of existing transmission capacity. At the moment, transmission between the Benelux countries and their neighboring countries is managed by explicit auctions and some other methods of congestion management.

The main transmission bottlenecks of Continental Europe can be observed in Figure 30. The fact that the only countries exhibiting electricity price convergence are the four countries of WCE implies that outside of this region, interconnections are congested or the electricity market does not function well – otherwise the prices should converge outside of WCE as well. Price convergence within WCE does not, however, imply that none of the interconnections connecting these four countries are congested: because each of the four countries is connected to more than one other country belonging to WCE, the congestion of one interconnection does not necessarily cause price divergence. However, the convergence of the electricity prices in WCE implies that congestion is not severe in the region, at the moment.

8 Price formation in Western Central Europe

In Chapter 7 it is observed, that differences in the price of electricity are very small between Germany, France, Austria and Switzerland compared to the price differences between these countries and other countries. This leads to the conclusion, that these four countries can (almost) be considered a single-price region (called Western Central Europe). In this chapter it is assumed that these four countries are indeed completely integrated in terms of prices, thereby forming one single market. The observations made in Chapter 7 imply that this assumption is not far from the truth.

Section 8.1 considers price formation in Western Central Europe in a theoretical situation, in which the electrical network of this region is totally isolated from the rest of the world. This assumption is relaxed in Section 8.2, which considers the more realistic situation, where Western Central Europe is connected to other countries with transmission lines of limited transmission capacity.

8.1 Internal influences

8.1.1 Aggregated consumption

A sectoral breakdown of consumption in Western Central Europe is shown in Figure 31.

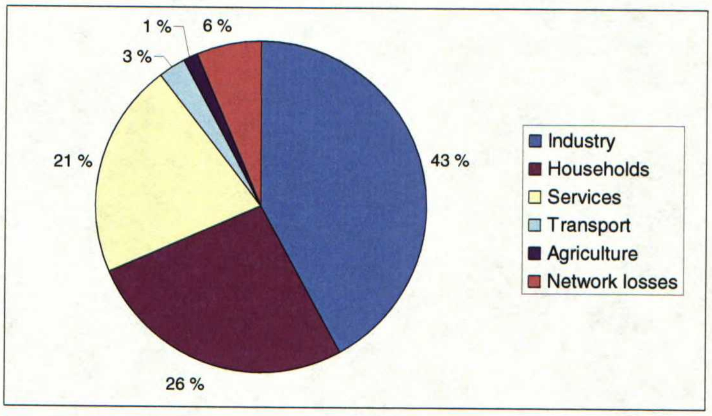

Figure 31. Sectoral breakdown of consumption in Western Central Europe. (Data source: Eurelectric 2004, pp. 72–76)

Figure 31 shows, that industry is by far the most important consumer of electricity in Western Central Europe, responsible for nearly half of all electricity consumption, while services and households are responsible for 21% and 26%, respectively. Also network losses constitute a sizeable part (6%) of total electricity consumption.

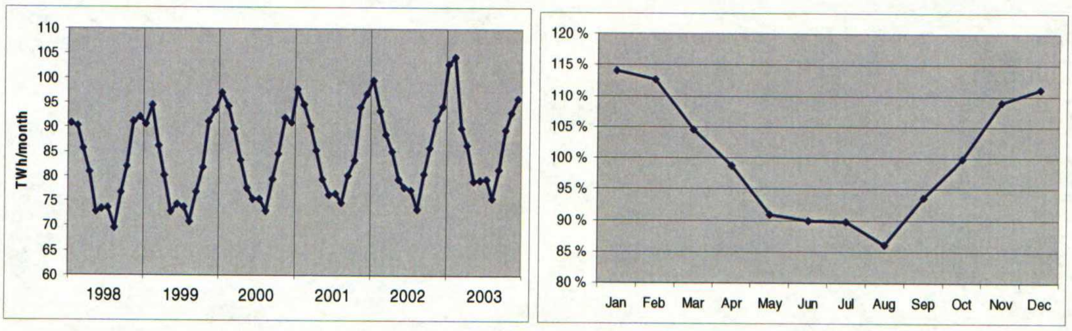

Figure 32. Total electricity Consumption in Western Central Europe: a time series and the yearly average consumption cycle. (Data source: UCTE)

Figure 32 illustrates the yearly cycle of electricity consumption in Western Central Europe. The figure shows the time-series based on monthly consumption statistics for the years 1998–2003, as well as an average consumption cycle, based on the time-series data. It can be seen that the form of the yearly cycle has been quite similar over these years: consumption is high in the winter, and low in the summer, falling to a particularly low level in August. There is also a clearly discernable rising trend in the data: average consumption in Western Central Europe increases by roughly 1% per year, while peak consumption appears to grow somewhat faster, at a rate of roughly 2% per year.

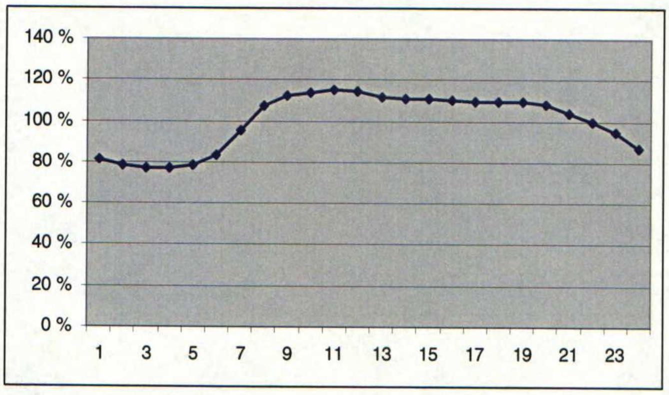

Figure 33. Average daily cycle of total electricity consumption on working days in Western Central Europe. (Data source: UCTE)

Figure 33 shows the average daily cycle of electricity consumption in Western Central Europe. The horizontal axis in the diagram shows the time of observation expressed in Central European Time (GMT+1). The daily cycle appears very similar to the cycles of the individual countries, examined in Chapter 4: During night-time, consumption is around 80% of the average level, while daytime consumption is at a level of 110 %, or more, of the average level, reaching its peak at around 11–12 a.m.

8.1.2 Aggregated production

Figure 34 shows the production structure of Western Central Europe. Nuclear power composes half of all electricity generated in the area. Figure 14 in Chapter 5 shows that most of this is produced in France, whereas German nuclear generation composes roughly a third of it. Germany is the largest producer of thermal power, and thermal power composes a third of all generation in this area. There is at least some hydro generation in each of the four countries, and together hydro generation composes 14% of all generation. Most of the generation that is based on other renewables is located in Germany, and consists mainly of wind power. One percent of all generation was not categorized under any specific form of generation in the source used.

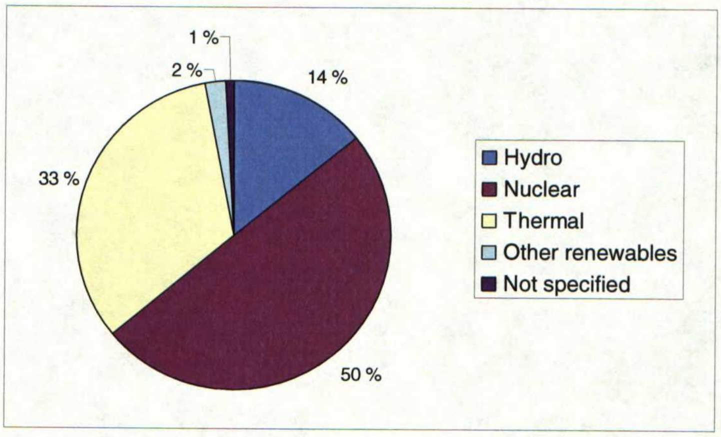

Figure 34. Production structure in Western Central Europe. (Data source: Eurelectric 2004, pp. 163–178)

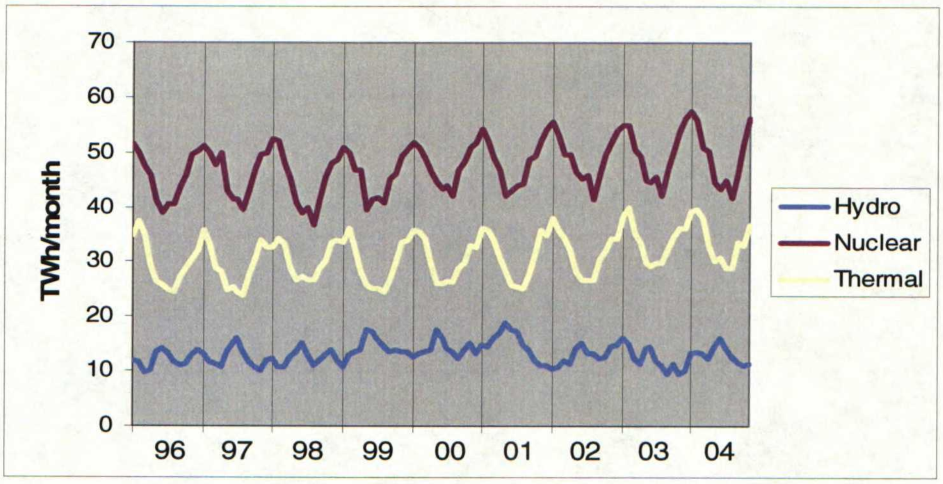

Figure 35. Long term variation of the production structure in Western Central Europe. (Data source: UCTE)

It can be observed in Figure 35, that nuclear and thermal power are both adjusted up during the winter and down during the summer. The main reason for this is that demand is higher in the winter. In the case of thermal generation, another reason lies in the seasonal variation in hydro generation: hydro generation volumes are larger in the summer, when inflows are high, which reduces the price of electricity, making thermal generation less attractive. The up-adjustment of hydro power in the summer can, with some difficulty, be observed in the figure. Seasonal variation in hydro generation is, however, small compared to seasonal variation in nuclear and thermal generation. Therefore it can be concluded, that seasonal demand-side variation is the most important determinant of nuclear and thermal generation. In the case of hydro generation, however, seasonal variation on the supply-side (varying inflows), is an important determinant of the volumes generated.

8.1.3 Price formation based on regional fundamentals

If the electric network of Western Central Europe is considered isolated from the rest of the world, price formation within this region can be considered as a case of free-trade equilibrium, as discussed in Section 2.2. The market equilibrium price is then the price, which equates the total supply and demand for electricity in the whole region. The location and form of the demand and supply curves is determined by the demand and supply fundamentals analyzed in Chapters 4 and 5. Changes in the demand or supply fundamentals result in changes in the demand and supply curves, the intersection point of which determines the market price. Price formation in the (theoretical) situation of an isolated Western Central Europe is illustrated in Figure 36.

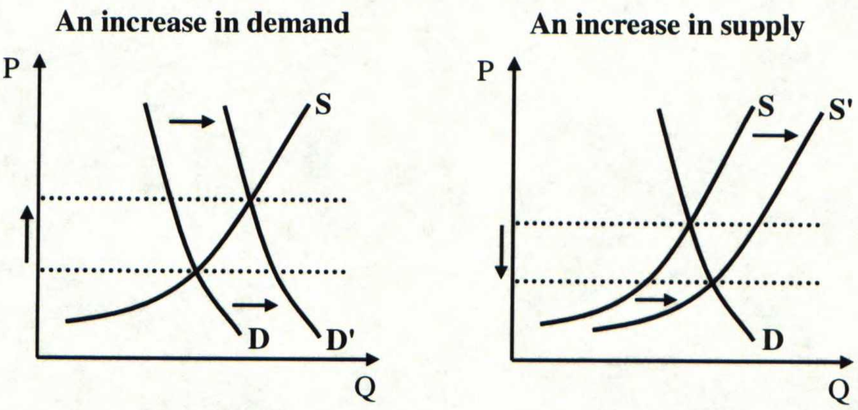

Figure 36. Price formation in an isolated Western Central Europe based on the aggregated demand and supply fundamentals of the region.

The effects of changes in demand and supply fundamentals are illustrated in Figure 36. In line with standard economic theory, a rise in demand, caused, e.g., by cold weather or increased industrial production, raises the price. In contrast, a rise in supply, caused, e.g., by large inflows, low fuel prices or an increased number of operating power plants, lowers the price.

8.2 Impact of electricity exchange with neighboring regions

Last section considered price formation in Western Central Europe in the (theoretical) case that the electrical network of the region is totally isolated from the rest of the world. In reality, however, Western Central Europe is connected to other countries with transmission lines of limited transmission capacity. The theory associated with this case is reviewed in Section 2.3, where on optimization model is presented for the modeling of such a situation. The model assumes that a market-based method (implicit auctions) is used for the allocation of transmission capacity. In this model, the price in each region is determined partly by local supply and demand, and partly by the supply and demand of other regions that are connected to the region under consideration. Even though the model is more complex than in the case of free-trade equilibrium, the intuition is the same, to some extent. For example, rising demand in some neighboring region leads to transmission capacity being allocated to transmission from the region under consideration to this neighboring region. If transmission capacity is insufficient, the price in this neighboring region may end up on a higher level than in the region under consideration, despite the transmission.

In this section, the region of Western Central Europe is considered as one region, since it is assumed, that the four countries constituting this region form a single market, which is completely integrated in terms of prices. Thus, the price in Western Central Europe is determined partly by the aggregated fundamentals of Germany, France, Switzerland and Austria, and partly by the fundamentals of other countries and regions. Figure 30 in last chapter illustrates this situation. The fundamentals of Western Central Europe were considered in last section, and the fundamentals of many other countries, that may influence the Western Central European market equilibrium, were considered in Chapters 4 and 5.

Figure 37 illustrates the total electricity flows between Western Central Europe and the other countries or regions considered in this research. Belgium and the Netherlands are categorized under one label (BE/NE) in the diagram. The figure shows, that the directions of the electricity flows are rarely reversed, except in the case of the interconnection between Western Central Europe and the Nordic countries. The direction of this flow varies, because it connects a thermal/nuclear-dominated region (WCE) with a hydro-dominated region (Nordic). This phenomenon is discussed in Chapter 6.

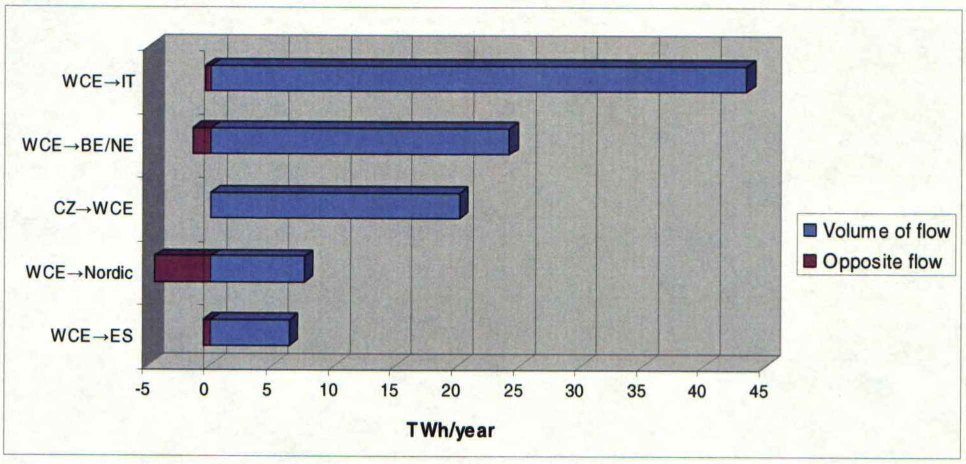

Figure 37. Total electricity flows to and from Western Central Europe in 2003. (Data source: UCTE)

Figure 38 illustrates each country's or region's share of the total electricity exports from Western Central Europe. It can be seen, that roughly half of the exports are directed towards Italy, while Belgium and the Netherlands together account for almost a third. Therefore, the supply-demand balance in Italy and in the Benelux countries is of high importance in determining the price of electricity in Western Central Europe.

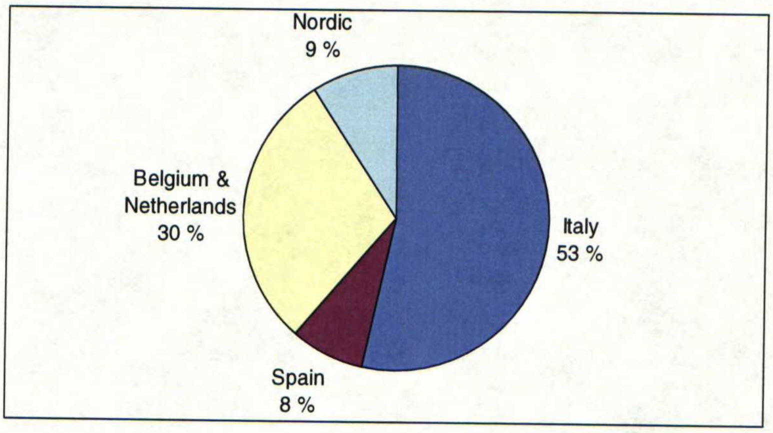

Figure 38. Each regions's share of the electricity exports from Western Central Europe during 2003.[8] (Data source: UCTE)

Time-series depicting monthly net transmission between Western Central Europe and other regions are plotted in Figure 39. Yearly cycles cannot be spotted in most of the time-series. When considering transmission between individual countries, yearly transmission cycles can be observed in most cases, as was shown in Chapter 6. However, when countries are aggregated into regions, the yearly transmission cycles, that were observable in transmission between individual countries, are lost in the noise, as the aggregate flows also include electricity flows having no discernable yearly cycle. A yearly cycle can, for example, be observed in transmission

[8] It should be noted, that the percentages in the diagram are not based on net export figures, but on total yearly transmission towards the region indicated by the labels. It should also be noted, that Western Central Europe exports electricity to some other regions as well, in addition to those considered in the diagram. These include the United Kingdom, South Eastern Europe and small countries, such as Luxembourg.

between the Czech Republic and Germany, but not in transmission between the Czech Republic and Austria, which nonetheless varies relatively much. When, however, Germany and Austria are considered as being part of one region, and transmission between the Czech Republic and this region is analyzed, transmission cycles cannot be discerned. For the same reason, it is also hard to discern a yearly cycle in transmission between Western Central Europe and the region formed by Belgium and the Netherlands: while a cycle can be seen in transmission between Germany and the Netherlands, there is no discernable cycle in transmission between France and Belgium.

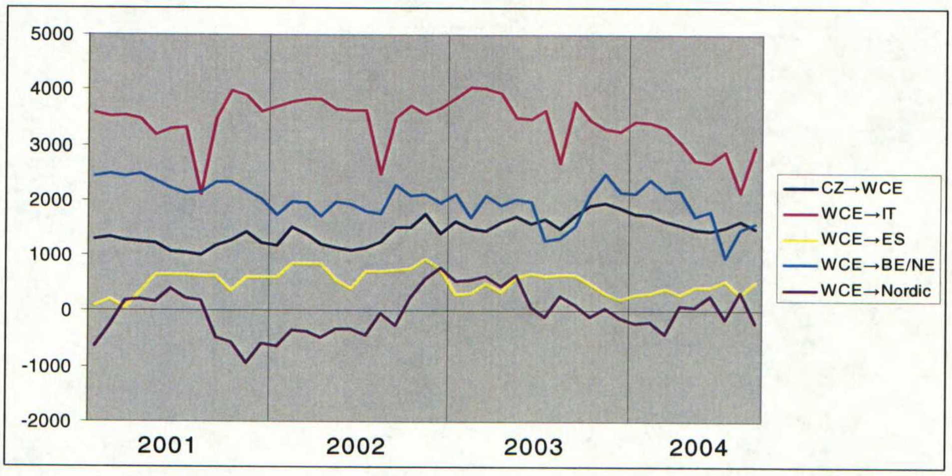

Figure 39. Time-series of monthly net transmission to and from Western Central Europe during 2001-2004. (Data source: UCTE)

The only yearly transmission pattern that can be observed with sufficient reliability by visual inspection of the time-series plots of Figure 39 is the drop in Western Central European exports to Italy occurring in August. The reason for this transmission pattern lies in the Italian consumption patterns, analyzed in Chapter 4: in August, there is a significant drop in Italian consumption, apparently as a result of Italians having their summer vacations. It can also be observed in the figure that the direction of the monthly net electricity flow between Western Central Europe and the Nordic countries changes from time to time, following no yearly cycle as the direction of the monthly net flow is largely determined by non-seasonal variations in Nordic inflows. Transmission patterns between Germany and the Nordic region are considered in Chapter 6.

Figure 40 depicts the general direction of the electricity flows between the regions considered in this Thesis. The arrows in the figure, which depict the electricity flows, are based on the analysis of electricity transmission between Western Central Europe and the other countries and regions. The thickness of the arrows represents the relative sizes of the flows. Western Central Europe is clearly a net exporter of electricity. The region imports electricity from the Czech Republic, while exporting far larger volumes to Italy, Spain, Belgium, and the Netherlands. The Czech Republic, in turn imports some electricity from Poland.

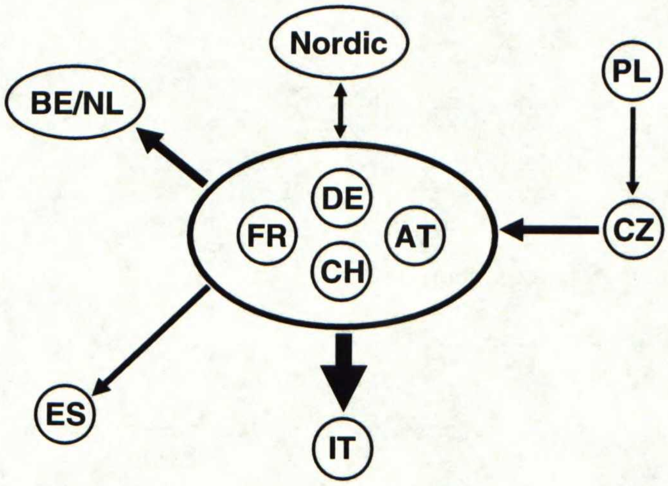

Figure 40. The general direction of electricity flows during 2003.

While the exact price formation mechanism would have to be defined mathematically, the intuitive interpretation is straightforward: A change in the supply and demand in one of the regions to which Western Central Europe is connected may influence the supply-demand equilibrium of Western Central Europe, but this influence is constrained by limitations on transmission capacity. For example, rising demand in one of these regions raises the price in that region and results in rising net imports from Western Central Europe (within the limitations of transmission capacity) and thereby in a higher price in Western Central Europe as well. Rising supply in one of these regions has the opposite effect. However, limitations on transmission capacity constrain the inter-regional propagation of changes in supply and demand. Thus, if a transmission line is already congested, increasing demand for transmission in the direction of congestion does not affect the electricity flow in that transmission line – instead, the price increases in the importing region whereas the price in the exporting region remains unaffected.

9 Discussion and Conclusions

The European Commission's agenda of liberalizing the European market for electricity has already brought significant changes in the sector. While traditionally the price of electricity was regulated, it is now in many European countries determined on the market, according to supply and demand. If there are large players in a market, deregulation may bring concerns of market power. Market integration lessens these concerns, as it reduces each player's share of the resulting total market. Integration is proposed by many economists as a remedy to the concerns of market power, and it is also the direction taken by the European Union.

The European electricity market is still developing, and liberalization is yet far from being totally implemented. There are, e.g., significant differences in legislation between the countries, and several different methods of congestion management are use, of which many do not produce results in accordance with the principles of a market-based economy. Many countries still also lack a national power exchange, which reduces the transparency of the market, and the exchange volumes in most existing power exchanges are still very low. Neither is the market yet fully integrated, which under deregulation may enable large players to exercise market power, and thereby result in inefficiency. The Nordic region leads the way in the sector, being clearly ahead of Continental Europe in the development of its electricity market.

Despite the obstacles, the trend is toward increased liberalization, which involves deregulation on one hand, and market integration, on the other hand. For some parts of Continental Europe, price convergence shows that market integration can already be considered as being well under way. An examination of electricity prices in different countries shows that Germany, France, Austria and Switzerland already form a de facto singe-price region (at least very nearly). This region of four countries is called Western Central Europe in this Thesis.

In general, the convergence of prices and thereby the integration of electricity markets is advanced by two main considerations: investments into cross-border transmission capacity and the improvement and harmonization of the methods of congestion management. The fact that the region of Western Central Europe already forms a single-price region implies that price convergence is possible even if differences exist in legislation, and even if the methods used for congestion management are not the best ones possible. Thus, the demand and supply fundamentals and transmission capacity are the most important determinants of the price of electricity. However, the use of well-functioning market-based methods of congestion management may make price convergence possible with a smaller amount of transmission capacity, i.e., it might lower the costs of integration. Using market-based methods of congestion management also guarantees the fairness of the allocation of transmission capacity among market participants, which is important in the creation of a competitive market.

According to the plan presented by the European Commission, there is likely to be an interim stage before the total integration of the European electricity market takes place. In this interim stage, there would be several internally integrated regions, each of them consisting of a number of countries. Finally these interim stage regions would be integrated into one, thereby forming a common European electricity market. According to the European Commission's plan, one of the interim-stage regions would consist of Germany, France, Austria, Switzerland, and the Benelux countries. This region differs from the region of Western Central Europe, which was found to be a near-single-price region already, only in that it includes the Benelux countries. The analysis of price data, conducted in Chapter 7, shows that, e.g., the Dutch price has not yet converged to that of France, Germany, Austria, and Switzerland. Therefore, in order for the European Commission's plan regarding the interim stage to realize, more transmission capacity would have to be built between the Benelux countries and Germany and/or France. Price convergence can, however, also be advanced by improving the methods of congestion management. It should be emphasized that this Thesis portrays the situation as it is at the present. The introduction of new interconnections or additional transmission capacity may change the location of bottlenecks, so that some of the conclusions presented in this Thesis may not remain valid. At that point, the analysis would have to be redone with new data.

The availability of statistical data on the European electricity markets is not particularly good especially compared to the Nordic electricity market. Much of the data available is also inaccurate, as it is very common for different sources to provide significantly different statistical figures. The poor availability of data implies that the market is not very transparent at the moment. Since much of the relevant data is hard and in many cases impossible to find even by actively searching for it, market participants can hardly be assumed to be well-informed in their decision making. Therefore, the more extensive collection and distribution of information is a prerequisite for a well-functioning European electricity market.

Several potentially interesting topics of further research are suggested in this research, partly as a result of its broad topic and exploratory nature. The price of electricity in the ten countries considered in this research is not only influenced by the fundamentals of these ten countries, but also by the fundamentals of other countries and regions. Therefore, future research could expand the group of countries examined. Relevant countries and regions excluded from this Thesis are the Nordic region, Eastern Europe, the United Kingdom, and Portugal. Future research could also focus on the influence caused by some particular price determinant, such as the weather, the price of coal or the price of CO_2 emissions. Hydro generation in the Alps and wind power in Germany might also be interesting potential topics. Further research might also involve the developing of a structural model for determining the price of electricity. However, the lack of information and comprehensive statistics imposes certain restrictions on research.

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Appendix: An optimization model for inter-regional allocation of generation and consumption (Source: ETSO 2002, pp. 11–12).

Maximize the benefit function

$$U = \sum_j B_j d_j - \sum_i C_i g_i$$

subject to the following constraints:

- bid/offer volume limits:

$$0 \le g_i \le G_i$$

$$0 \le d_j \le D_j$$

- system generation-demand balance:

$$\sum_i g_i - \sum_j d_j = 0$$

- inter-regional transmission constraints:

$$\sum_{n \ne p} f_{kn} \left[\sum_{i \in I_n} g_i - \sum_{j \in J_n} d_j \right] \le F_k$$

The variables and parameters of the model are defined as follows:

d = allocated demand volume

g = allocated generation volume

f = inter-regional loadflow distribution factor

B = bid price for imported energy

C = offer price for exported energy

D = bid/offer demand volume

F = inter-regional transmission constraint limit

G = bid/offer generation volume